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FINAL REPORT

COMPRESSED AIR DEMAND-TYPE FIREFIGHTER'S BREATHING SYSTEM

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FORWARD

This report is submitted by Scott Aviation Division of A-T-O Inc. in partial fulfillment of contract NAS9-~~12177~~ 13177 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. It covers the work performed on the program between October 1972 and September 1975.

Technical direction was provided by technical monitors Pat McLaughlin and W. B. Wood of the crew systems division of NASA JSC.

Mr. J. L. Sullivan served as the Scott Aviation Program Manager. The test program was directed by Mr. Paul Bement. Significant design and development contributions were made by Eugene Giorgini and Milo Simmonds.

The User Requirement's Committee assembled by Public Technology Inc. made valuable suggestions that enhanced the practicality of the system, and were greatly appreciated by the author.

ABSTRACT

The commercial availability of lightweight high pressure compressed air vessels has resulted in a lightweight Fire-fighter's Breathing Apparatus. The improved apparatus, and details of its design and development are described.

The apparatus includes a compact harness assembly, a backplate mounted pressure reducer assembly, a lightweight bubble-type facemask with a mask mounted demand breathing regulator. Incorporated in the breathing regulator is an exhalation valve, a purge valve and a whistle-type low pressure warning that sounds only during inhalation. The pressure reducer assembly includes two pressure reducers, an automatic transfer valve and a signaling device for the low pressure warning.

Twenty systems were fabricated, tested, refined through an alternating development and test sequence, and extensively evaluated in a Field Evaluation Program.

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DEFINITIONS

F.B.S. - Firefighter's Breathing System

G.F.E. - Government Furnished Equipment

scc/Minute - Standard Cubic Centimeters per Minute (32^{o}F, 14.7 psia)

S.T.P.D. - Standard Temperature And Pressure Dry (32^{o}F, 14.7 psia, dry)

H_z - Hertz, frequency value (cycles per second)

^{o}F - Degrees Farenheit

LPM (lpm) - Liters Per Minute

SLPM - Standard Liters Per Minute (@ 32^{o}F, 14.7 psia)

BTPS - Body Temperature and Pressure Saturated (98.6^{o}F, 100% R.H.)

R.H. - Relative Humidity

C.G.A. - Compressed Gas Association

psig - Pounds Per Square Inch Gage

psia - Pounds Per Square Inch Absolute

1 INTRODUCTION

Self-contained breathing systems have been available to the fire fighter since 1880; however, the first use of a mechanical aid to breathing under water was recorded in an Assyrian bas-relief dating back to 900 B.C. The systems of today have been available, in various stages of development, since 1945.

For many years the most popular respiratory protective device for the fire fighter was the "Type-N" or so called "all purpose" gas mask. It was small, lightweight and provided protection against low concentrations of carbon monoxide, ammonia, alkaline and acid gases, chlorine and smoke, but it was totally ineffective in oxygen deficient atmospheres. It provided the fire fighter with a false sense of security. Consequently, its recommendation for use was deleted by the National Fire Protection Association (NFPA) in 1971. At the same time, a self-contained breathing system with 30 minutes approved duration was established as the minimum acceptable system.

Greater use of the popular "open loop" compressed air breathing systems resulted in increased complaints as to their weight, bulk, and operating duration. The desire of the fire fighter was for a system approximating the weight and size of the "Type-N" gas mask, but providing him with complete respiratory protection.

The success of the Space Program suggested that advanced technology was available to provide a better, lighter weight, smaller system. NASA, through its Technology Utilization Program, has provided the expertise to coordinate the development of an improved system to satisfy the operational needs of the fire fighter, while remaining within the cost constraints of the fire departments.

An extensive engineering study was conducted to determine the optimum system concept. All of the concepts considered fell into two broad system categories: open-loop systems or closed-loop systems.

The closed-loop system is recognizable as the system used by the Astronauts in their moon walks. On Earth, it is most commonly used by mine rescue personnel during rescue operations. Closed-loop systems provide maximum duration in a minimum size and weight package.

In closed-loop systems, the user "rebreathes" his own exhaled breath after it has been "conditioned" by the removal of carbon dioxide and the replenishment of oxygen. Carbon dioxide is usually removed by a chemical "scrubber". Heat is added to the gas stream by the carbon dioxide removal process and by the user's respiratory system. For reasonable user comfort, this heat must be removed by heat exchange with the ambient environment, or by interaction with a supplemental media (e. g., melting ice). Oxygen consumed by the user is replaced by an oxygen supply that may be compressed gas, cryogenic or chemical.

Closed-loop systems provide minimum weight and a desirable (flatter) external profile as advantages. The disadvantages are higher initial and rechange cost, use of pure oxygen, difficulty in restarting after shutdown, more complex maintenance and recharge, and operational limitations related to the ambient temperature. Closed-loop systems have limitations when used in an ambient environment that will freeze water, and are uncomfortable when used in ambient environments above body temperature, without elaborate supplemental cooling devices.

The open-loop system is typified by the compressed air breathing systems in common use today. It consists of a breathing gas supply such as compressed air, a flow control valve and a facemask. Exhaled breath is dumped overboard through a check valve in the facemask.

All of the breathing gas that is used by the wearer is carried in the pressure vessel that is usually back mounted. Since man breathes in response to a need to ventilate his sytem, he "uses" considerably more air than that represented by the oxygen consumed. Whereas air contains 20 percent oxygen, in an open-loop system the user only consumes oxygen that represents approximately 5 percent of the volume of the air that is "used". Obviously, there is an inefficient utilization of breathing gas in open-loop systems.

The inefficient utilization of breathing gas in open-loop systems leads to their disadvantage. They are not the minimum weight or bulk systems, and they require a compressor for recharge. Conversely, their advantages include lower cost (initial and recharge), simple maintenance and recharge, use of air rather than pure oxygen, shutdown and re-start capability, and operational capability not limited by the ambient environment. The optimum open-loop system is a demand-type system utilizing extra high-pressure compressed air contained in a lightweight pressure vessel. Such a system minimizes the disadvantages while it retains the advantages.

Comparison of the advantages and disadvantages of both systems resulted in the selection by NASA of the open-loop demand system for further development. Such a system is clearly superior to the closed-loop system in all areas except weight and profile. The use of a new lightweight, extra high-pressure, cylinder for air storage results in a system with reduced weight and bulk when compared with currently available breathing systems of similar duration.

2 SYSTEM SAFETY ANALYSIS

A system safety analysis provides the base for the design of a safe system. The system safety analysis for the Firefither's Breathing System is reported on a separtate document in accordance with the Contract Data Requirements List, Item 1. (Scott Engineering Report No. 1018) appendix A

The analysis is broken into three (3) sections:

1. Preliminary Hazard Analysis

2. General Corrective Action/Minimizing Provisions

3. Specific Correction Action/Minimizing Provisions

The first two sections provide the guidelines for the design and the third section defines in detail how the guidelines are satisfied.

3 DESIGN OBJECTIVES

A General Objectives

Consultation with various fire departments through the User Requirements Committee established the general requirements for an improved system as follows:

Reduce system weight;

Reduce system bulk;

Increase the operating duration;

Improve human factors (for donning, doffing, operation of controls, interface with helmet, etc.)

Improve system and component performance;

Maintain system cost within a cost range acceptable to the fire departments.

The first three items and for the most part the sixth are influenced mostly by the selection, by NASA, of a high pressure composite pressure vessel for storage of the compressed air. The vessel results in a significant weight reduction. Compared with currently available system, it may be selected to provide a reduction in bulk for the same duration, or an extended operating duration with approximately the same bulk.

The significant reduction in weight of the pressure vessel makes the reduction in weight of the other system components much more important. The pressure vessels were provided by NASA to Scott as Government Furnished Equipment (G.F.E.)

B Specific Objectives

The fourth and fifth general objectives result in specific design objectives as follows:

Comfort

Design and develop a simple, comfortable harness and frame assembly that effectively transfers the weight of the components to the wearer's hips. It should be easy to don (15 seconds maximum) and quick to doff (3 seconds maximum).

Controls

Locate all manual controls for ease of operation by the firefigher, design to preclude inadvertent actuation, and simplify their operation so elaborate training is not required. The system shall be capable of startup by the wearer, unassisted, under emergency conditions.

Recharge

Provide for easy recharge and rapid replacement of the pressure vessel in the frame.

Facemask

Design the facemask to minimize interference with the helmet and turn-out coats. It shall prevent inward leakage in excess of 1.5 scc/minute (STPD) when worn by persons having head dimensions ranging from the 10th to 90th percentile as defined in WADC Techinical Report 52-321, "Anthropometry of Flying Personnel-1950" by H. T. C. Hertzberg, G. S. Daniels and E. Churchill, September 1954, pp. 57-76. Similarly, outward leakage shall not exceed 200 cc/minute.

Depletion Warning

Design and develop a breathing air-powered depletion warning device that provides an audible signal to the user, when the supply pressure drops below 830 psig. It shall be audible only during the inhalation phase of each breath, at a signal intensity of 70 to 90 db at the ear of the user, with a frequency range of 500 to 4000 Hz.

Operating Temperature and Flow

The FBS shall operate for temperatures from 200^{o}F to -60^{o}F and for supply pressures from 4,500 psig to 100 psig. It shall be capable of satisfying the following minimum flow requirements:

Inhalation:

Supply Pressure (psig)	Demand Pressure (inches water)	Flow Rate (LPM BTPS)
4500 to 570	-0.1 to -0.5	Flow iniation
"	-1.25	289
"	-2.00	535
570 to 100	-2.00	200

Exhalation:

Facemask Pressure (inches water)	Flow Rate (LPM BTPS)
+0.1 to +0.5	Flow initiation
+2.0	289
+4.0	535
+5.0	To match maximum input with bypass.

Response Time

The system shall be stable and shall satisfy the response rate imposed by a sine wave breathing pattern with a peak flow of 289 slpm and a frequency of 30 respirations/minute.

Bypass

Provision shall be incorporated to permit the wearer to manually bypass any possible failures and to supply an adjustable flow of air directly to the facemask. The device shall be capable of providing 125 lpm (BTPS) over the range of inlet pressures from 4,500 to 100 psig, yet not provide flow rates that result in facemask pressures in excess of 5 inches of water.

Life

The FBS shall be designed for a minimum useful life of 10 years or 5,000 use cycles, with regular maintenance, cleaning and replacement of limited life items allowed during that period.

Cost

The system cost, excluding the pressure vessel, shall be less than $120.00 based on a production volume of 10,000 units per year.

Other

Other specific objectives shall be as detailed in the Specification FBS-SP-001, Revision 2, dated November 3, 1971.

4 SYSTEM DESIGN

A Review of Current Self-Contained Compressed Air Breathing Systems

NIOSH/MESA[(1)] Certified Firefighter's Breathing Systems

In order to set the stage for the new system, one configuration of the presently available equipment is pictured in figure 1, and illustrated schematically in figure 2. It is composed of a harness mounted, two-stage demand breathing regulator, and a wide vision full facemask. A flexible high-pressure hose connects the cylinder valve with the breathing regulator, the output from which is connected to the facemask with a large diameter corrugated breathing tube. Integrated with the breathing regulator are two manual controls: a main line shut-off valve and a bypass valve, and a low-pressure warning device. On some systems the warning device may be mounted at the cylinder valve.

The system provides 45 cubic feet of air that is supplied to the fireman through the demand breathing regulator. The demand regulator has a minimum peak flow capacity of 200 liters per minute at 2 inches of water negative draft, but typical units provide approximately 300 liters per minute peak flow. The complete assembly weighs 33 pounds fully charged with air, 18-20 pounds of which is the air storage cylinder and 3 pounds of which is air.

European Compressed Air Systems

European compressed air breathing systems generally utilize a backpack mounted first-stage regulator and mask-mounted demand regulator. Air is commonly supplied from a backplate mounted cylinder charged to 4500 psig. A continuous flow whistle type low-pressure warning is available as an accessory. Both chevron type and pneumatic seal facepieces are available. The pneumatic seal facepiece is more popular in Great Britain, while the chevron type is more popular on the Continent.

SCUBA Compressed Air Systems

Early models utilized a cylinder mounted single-stage (2-hose) regulator. Inhalation was through one corrugated hose, with air supplied by the diaphragm actuated "demand valve". Exhalation was through the other corrugated hose to an exhalation valve mounted in the demand regulator. The center

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(1) National Institute of Occupational Safety & Health

of pressure of the diaphragm of the demand regulator was maintained as close as possible to the center of pressure of the exhalation valve. The two large diameter hoses were considered by most users to be encumbering. The majority of current systems utilize cylinder mounted first-stage and mouthbit mounted demand regulators. A single small diameter hose connects the two components. Most professional systems utilize a balanced valve first-stage regulator to provide high flow for the full cylinder pressure range.

B Final Firefighter's Breathing System Concept

A breathing system shown pictorially in figures 3 and 4 schematically in figure 5 includes the following:

Facemask

The lightweight facemask integrally contains a minimum of system components. It is suitable for issue as personal equipment at minimum cost. The facemask has a chevron seal. An inflatable seal model was evaluated during the prototype test phase and found to be no better than the more reliable chevron seal.

A unique net-type head harness fits beneath the helmet without impairing the fit of the helmet or requiring that the band be adjusted. It has ear cut-outs so that the ears are not covered nor pressed tightly against the head.

The mask has a large "quick-disconnect" fitting to mate with the breathing regulator. When the regulator is removed, the fireman can readily breathe through the opening, a feature that allows him to don the mask on the way to a fire in order to save donning time.

Demand Regulator

The facemask mounted demand regulator contains an integral exhalation valve, a signal device for the low-pressure warning system, and a manually operated purge valve. The regulator assembly is connected to the facemask with a large diameter "quick disconnect". The input to the demand regulator is through a single hose from a backpack frame mounted pressure reducer assembly.

The regulator is a compound lever operated design with remote sensing. Air flows into the facemask over the visor through a spray nozzle in the regulator. Exhalation is through a diaphragm mounted exhalation check valve.

The body of the regulator is injection molded of a heat resistant plastic, while the cover is metal. The cover protects the check valve and serves as a stop to permit full opening. The "dead space" in the area above the check valve offsets the inertia of the check valve and minimizes the diffusion of contaminants back through the check valve as it is closing.

Pressure Reducer

The frame mounted pressure reducer assembly includes a primary first-stage regulator, a backup first-stage regulator, an automatic transfer valve, and a turn-on mechanism for the low-pressure warning system.

Depletion Warning

The low-pressure warning system is connected with the backup first-stage regulator system to prevent duplication of function and/or components, and to provide warning of failure of the primary system. In the pressure reducer assembly, the backup first-stage regulator is set at a pressure significantly above that of the primary first-stage regulator. Low pressure in the bottle results in the actuation of the turn-on mechanism (valve) that transfers the output of the pressure reducer assembly from the primary pressure regulator to the backup regulator. The higher pressure supplied to the mask mounted demand regulator causes the shifting of a valve, in that assembly, that results in the flow of some of the inhaled air through a whistle contained within the facemask. A whistle so mounted provides adequate sound warning to the user's ear on inspiration, with no loss of breathing air.

The pressure vessel mounted shut-off valve has an upstream connected combination frangible disc-fusible plug safety relief device, and pressure gage. Valve protection is provided by an elastomeric bumper, and the pressure gage guard is extended to serve as a positioning device for easier attachment of pressure vessel valve assembly to the harness and frame assembly. The valve outlet, a modification of the CGA 1340 connection, is connected through a hand-operated coupling and a flexible hose with the frame mounted pressure reducer. The modification of the CGA 1340 connection (figure 6) prevents connection with current lower pressure systems, yet permits the use of the lower pressure cylinder and valve with this system. If the high pressure cylinder

valve is connected to a current lower pressure system, the sealing surfaces will not mate and air will be blown out through the vent holes. Conversely, a lower pressure cylinder valve will mate with the high pressure fitting of the FBS.

Harness and Support Frame

A flexible conformal frame and harness assembly is utilized to carry the pressure vessel, valve and pressure reducer assembly. The frame is a composite structure utilizing aluminum for the rigid components and an alloyed ABS/polycarbonate plastic material for the flexible section. A two-position adjustable aluminum band coupled with a unique spring-type toggle clamp holds the compressed air cylinder. The cylinder is positioned on the frame by the combination of a stop and a hook on the cylinder valve. The harness assembly is arranged so that the majority of the weight is carried on the hips. It can be arranged either with two shoulder straps that connect on one end to the front section of the waist belt, and on the other to the rigid aluminum section of the frame, or with a single cross-chest strap that connects between the frame at the right rear and the buckle at the left front. The connection with the buckle is arranged so that the apparatus can easily be dropped from the right shoulder, during doffing, after the buckle is released. A modified push-button release, automotive seat belt type buckle, is combined with a web adjuster for easy connection and separation of the waist belt.

A system weight, not including the pressure vessel, of 7.78 pounds was projected with the following estimated breakdown:

Facemask and head harness	.59 lbs.
Demand regulator assembly	.25 lbs.
Pressure reducer assembly	2.0 lbs.
Cylinder valve assembly	.76 lbs.
Harness and frame assembly	3.2 lbs.
High pressure hose assembly	.73 lbs.
Low pressure hose assembly	.25 lbs.

A system manufacturing cost of $125.22 was estimated at a yearly production level of 10,000 units (based on 1972 rates). Depending on the manufacturer, a selling price to cost ratio of from 3 to 5 can be assumed.

The estimated tooling cost was $160,000. Write-off in one year would result in a cost increase of $10.60 per unit. Capitalization and write-off in three years would result in a cost increase of $3.53.

A breakdown of the cost figure is as follows:

Facemask and head harness	$10.55
Demand regulator assembly (including hose)	23.50
Pressure reducer assembly	58.30
Cylinder valve assembly	8.05
Harness and frame assembly	19.25
High pressure hose assembly	5.57

C **Alternate System Concepts**

Alternate system concepts that received consideration during the Design Phase are defined and discussed in figures 7 through 16. The facemask and harness and frame assembly are considered common elements of each system. The cylinder and valve assembly is also a common element except in System H, which has a combined cylinder valve and first-stage regulator.

D **System Selection Rational**

Previous experience had shown that it is very difficult to build a responsive high flow demand breathing system with a remotely mounted breathing regulator. Additionally, that experience had shown that isolated supply and sensing was most desirable. Only by the use of two breathing tubes (co-axially arranged) or by placement of the demand breathing regulator on the facemask could a reliable system be built to provide the wide range of flow (0 to 535 lpm BTPS) and the precise system response. Preliminary calculations indicated that the size of a coaxial type breathing tube, that might connect with a frame mounted demand regulator, would be unreasonably large. A mask mounted demand breathing regulator connected to the air supply by a small diameter flexible hose operating at an intermediate pressure of approximately 100 psig was strongly indicated.

A pressure reducing regulator mounted on the back frame, or on the cylinder valve, is needed to regulate the intermediate pressure. However, such an arrangement complicates the bypass system. It is desirable to have a single hose connecting with the breathing regulator. A relief valve mounted in the demand breathing regulator would allow bypass flow through the single hose, since the pressure from the bypass valve would overload the relief valve and allow flow into the facemask. If manually operated, the bypass valve would probably be mounted on the back frame, which would be a human factors consideration.

A manual bypass system is additionally complicated by the supply pressure span from 4000 to 100 psig. The valve that will pass the required flow at 100 psig will provide far too much at 4000 psig, and manual control would be difficult. Calculations indicated the need for pressure regulation of the bypass system. Once the need for an additional pressure regulator was established, it appeared most practical to duplicate the primary pressure reducer to minimize the inventory of spare parts. A pressure reducer concept evolved that included two pressure reducers with automatic transfer, in the event of failure of the primary pressure reducer. A manual bypass became unnecessary; instead, the manual control became a purge for flushing the facemask of contaminants or clearing the visor of condensed water vapor. The manually operated control was located at the inlet to the mask mounted demand breathing regulator for convenience of operation.

The separation of the flow section from the control/sensing section of the demand breathing regulator created an opportunity for a unique low pressure warning subsystem. By incorporation of a spray nozzle in the breathing regulator, it is possible to provide a pressure differential between the facemask and the supply to the spray nozzle that provides the energy to sound an alarm that is tied directly to each inhalation. A whistle that utilizes some of the air from the spray nozzle appeared most feasible. It was subsequently established that this whistle could be incorporated in the breathing regulator such that the air flowing through it could be breathed by the user.

A technique of signaling was required to recognize the low supply pressure and to transform this into a change in pressure reducer outlet pressure. The change in intermediate pressure could then be sensed by a valve in the breathing regulator that in turn would transfer some of the flow from the spray nozzle to th

whistle. An upward shift in intermediate pressure is desirable to overcome the risk of a false indication caused by pressure regulator "droop" with high flow.

It is possible to actuate the alarm by the reverse change in outlet pressure that is a characteristic of an unbalanced, upstream valve type pressure regulator. However, such a system would require that a large area sensor be incorporated in the breathing regulator in order to provide the specified sensitivity. A step change in intermediate pressure leads to a smaller sensor in the breathing regulator, but adds some complexity to the the pressure reducer.

Two different concepts were evaluated for providing the step change in intermediate pressure. The first concept utilized a pneumatic actuator to apply an extra load to top of the control element of the regulator, thereby increasing the outlet pressure. The second concept utilized a second pressure reducing regulator with an outlet pressure set higher than the first. A transfer valve actuated by low supply pressure switches from the lower intermediate pressure to the higher intermediate pressure as required. Since a two-regulator concept was desirable to eliminate the manual bypass, the concept was doubly desirable since it would provide a redundant pressure reducer system and provide the alarm to indicate low supply pressure, and coincidentally to warn of failure of the primary pressure reducer.

The selected system provides superior performance with an acceptable weight and cost. The redundant pressure reducer system serves a dual role: First, by providing safety without a manual bypass; second, by combining with a transfer valve and whistle, in the mask mounted demand breathing regulator, to provide an effective low pressure warning. The components are suitably arranged so that the heavier items are carried on the back on a comfortable harness and frame assembly. The high capacity, lightweight demand breathing regulator is mounted on a lightweight bubble type facepiece and results in a convenient assembly with a total facepiece weight that is significantly less than any currently in service.

5 COMPONENT ANALYSIS OF FINAL DESIGN

A Facemask and Head Harness (figure 17)

A bubble type facemask is utilized. It has a small size to fit on front of face for more universal fit and minimum interference with fireman's hat. It has a free blown polycarbonate visor and adhesive bonded face seal with a chevron-type seal. The facemask includes the female half of a quarter turn "quick disconnect" for connection with demand breathing regulator. A secondary detent type locking device is included to preclude unintentional release.

A four-point connection fabric hood type head harness with a single strap, two-tab adjustment, is utilized. The hood type is compatible with the fire helmet and precludes the need to adjust the helmet size for use with the facemask.

A voice transmitter is not utilized since tests have shown that sound transmission through the visor is equivalent to current facepieces with voice transmitters. The test and data is detailed in figure 18.

A loose-fitting oral-nasal cup is an optional accessory for the facemask assembly. It is a snap-in design that will probably be used only at low ambient temperatures. The spray nozzle in the regulator is expected to keep the visor clear in all but extreme condition. Greater comfort is provided by this design, and the need for inhalation check valves is eliminated by the openings at the bottom.

B Demand Regulator Assembly

The Demand Regulator Concept Analysis Chart (figure 19) indicates alternate design concepts with their associated advantages and disadvantages.

A demand regulator with integral relief and remote sensing (sectional view, figure 20) was a strong candidate. A design such as this is desirable for a system with a mask mounted demand regulator and a backpack mounted pressure reducer with a manually operated bypass valve. Bypass flow to the demand regulator would be through the single low-pressure hose. The high pressure provided by the bypass valve would open the relief valve and flow into the facemask. The design does not coordinate with the spray nozzle concept; consequently, it was not developed.

The finalized design demand regulator is based on the best features of two designs developed in the Conceptual Design phase. The original two preliminary designs are shown as figures 21 and 22. Figure 23 depicts the final design. It is a compound lever operated, downstream type, semi-balanced valve regulator with isolated sensing. The exhalation valve, spray nozzle, warning whistle assembly and manual purge valve are integrated into the assembly. The regulator is mask-mounted by means of a large diameter "quick disconnect". The design is compatible with the future addition of pressure demand operation if that mode of operation proves desirable.

The body of the regulator is designed to be molded of a heat-resistant plastic (Valox or equivalent), while the cover and some of the valve parts are aluminum with silicone rubber seals.

A cotton fabric reinforced rubber hose with a service pressure rating of 250 psi connects the demand regulator with the pressure reducer assembly. A banjo-type fitting is swage connected on the regulator end, and the male component of a new push-to-connect "instant fitting" is swaged to the pressure reducer end of the hose. A plastic sleeve pressed onto the male fitting provides the disconnect capability without the need for a separate tool. The "instant fitting" provides swivel action in one axis, while the banjo fitting provides swivel action in a perpendicular axis. The result is a flexible assembly that applies little load to the mask-mounted regulator.

A downstream type semi-balanced valve is utilized in the regulator. By a very slight unbalance favoring the closed position, the valve is pressure closing, thereby reducing the risk of minor leakage that characterizes balanced valve. The design is essentially insensitive to inlet pressure variations and is compatible with the warning system. Calculations indicate that a minimum valve diameter of .162 inches will satisfy the flow requirements. Since balanced type valves are not sensitive to size, a balance tube diameter of .247 inches has been selected, since it matches the readily available tube. A valve diameter of .218 inches combined with the valve seating lands provides the slightly unbalanced valve assembly.

A compound lever design valve actuator was selected since it provided the most efficient linkage with a minimum of sliding friction, yet it is simple to fabricate and assemble.

The lever assembly is made up of three parts: the piston lever, the diaphragm lever and the shroud. The piston lever pivots in the regulator body and contacts a slot in the valve resulting in a mechanism commonly known as a "scotch yoke". The diaphragm lever pivots in the shroud that is screwed to the regulator body. Its lower end contacts the upper end of the piston lever, while the upper end is driven by the diaphragm.

The diaphragm assembly is molded of silicone rubber with a heat-resistant plastic reinforcing plate molded in place. A mushroom type exhalation check valve is attached to the reinforcing plate. The exhalation valve satifies the maximum leakage requirement of 1.5 scc/min.

An aluminum cover protects the check valve and diaphragm and serves as a stop to permit full opening of the check valve. The dead space in the area above the check valve offsets the inertia of the check valve and prevents diffusion of contaminants back through the valve as it is closing.

In normal operation, inhalation by the fireman results in reduced pressure in the facemask. The pressure diffenential acting on the diaphragm causes it to move inward pushing on the lever assembly and thereby opening the inlet valve. Air flows into the spray nozzle, and then at high velocity over the visor of the facemask. Pressure in the mask cavity builds up and forces the diaphragm outward resulting in the closure of the inlet valve. Exhalation by the fireman increases the pressure in the cavity an additional amount, pushes the diaphragm to its upper stop, and opens the exhalation valve to vent the exhaled breath.

Manual purging of the facemask is accomplished by manipulation of the knob on the demand regulator.

Rotation of the non-rising knob turns a spline connected screw that push opens the supply valve of the demand regulator. The thread pitch on the screw is selected to provide the maximum opening in one-half of a revolution of the knob. A radial type limit stop is incorporated to preclude the possibility of jamming the valve in either a full open or full closed position. The maximum opening limits the flow through the purge valve to approximately 125 liters per minute.

Several other components are included in the regulator assembly, but they relate to the low pressure alarm, and will be described in that section of the report.

A microphone for an electronic type voice amplifier can be mounted on the sidewall of the body of the demand regulator, utilizing a molded rubber boot with a grommet type feed-thru for attachment and sealing of the wire penetration (figure 24). This microphone can be used in conjunction with the Scott/Acme Speakezee (P/N 63630) or walkie-talkie (P/N 3510).

C Pressure Reducer Assembly

The lowest cost, lightest weight system utilizes an integrated cylinder valve/pressure reducer, such as one previously developed by Scott (figure 25). The combination regulator cylinder valve lacks a bypass system to protect user from a failed-closed first-stage regulator. It does not include low pressure warning. In its present stage, it does not satisfy the specification; hence, it has been "disqualified" from the official analysis. However, the details have been included since it represents a functional system whose cost and weight take precedence over safety.

Bypass System - The simple hand control valve technique of current systems, if improperly manipulated, could result in injury to the user from excessive flow and/or mask pressure. A valve that will flow 125 slpm at 100 psig will flow 4500 slpm at 4500 psig if fully open. Flow fuses (figure 26) have been evaluated and shown to be ineffective for this application. At 4500 psig an orifice diameter of .012 inches is required for 125 slpm flow, while at 100 psig a .064 inch diameter is required. Candidate devices could not accommodate this span. It was concluded that pressure regulation of the bypass circuit was necessary.

Two first-stage regulators with automatic transfer (Ref. figure 5) have been selected in lieu of a single regulator and a pressure regulated bypass valve. If the backup regulator is set at a lower pressure, transfer is automatic without a transfer valve. If the backup regulator is set at a higher pressure, a transfer valve is required. However, a warning system can be readily incorporated into this latter concept without risk of a false warning due to high flow and the resultant primary regulator pressure droop.

Balanced inlet diaphragm-type regulators were selected based on performance and cost considerations and low temperature tests (figure 27).

Leakage was detected at the "O" ring on the large end of the piston of a piston-type regulator design when tested at -65°F. Consequently, it was decided to change to a diaphragm type seal and motor element for the regulator. If the "O" ring seal on the inlet side of the regulator should subsequently prove troublesome at low temperature, it is an easy matter to change to a self-energizing teflon-type seal.

The primary regulator is tentatively set for 90 psig and the backup regulator for 125 psig with a piston-type transfer valve. The balanced valve regulator design results in a narrower outlet pressure span, which in turn results in a smaller low pressure hose and a smaller demand regulator assembly.

Calculations show that a valve diameter of .060 inches is required to provide a flow of 535 lpm BTPS at 570 psig supply pressure. A flow of 200 lpm (BTPS) requires a valve size of .099 inches dia. at 100 psig cylinder pressure. The two pressure reducing regulators have been designed with a valve size of .179 inch dia. with a .125 inch diameter flow port.

Regulated outlet pressure variation from high to low cylinder pressure (4500 to 100 psig) will be approximately 90 to 77 psig at a no-flow condition for the primary pressure reducer and 125 to 110 psig for the backup pressure reducer. An additional 5 psi above these values has been considered for valve lock-up. The outlet pressure variation is based on a maximum area differential (unbalance) of 10 percent. Estimated performance characteristics of the pressure reducers are shown in figure 28.

The spring force required to obtain these regulated pressures are nominally 56 and 83 pounds respectively. If a droop characteristic of 10 psi is applied for maximum flow, spring rates as high as 340 #/in. would be permissible; however, spring rates of up to 180 #/in. have been selected in the design.

These springs are designed to be fabricated from music wire with maximum working stress of 85,000 psi for the primary regulator and 110,000 psi for the backup regulator.

The basic pressure reducer is designed to be constructed of a stainless steel valve shaft bonded to a silicone elastomer diaphragm which is reinforced with a nylon fabric. A bead at the outer edge of the diaphragm is clamped and sealed to the aluminum body by the cover. The valve shaft associated with high pressure is sealed dynamically by means of a silicone "O" ring with teflon backup ring. At a no-flow condition, the shaft closes against a fluorocarbon (Kel-F) seat.

Relief Valve

A relief valve is incorporated into the pressure reducer outlet fitting to protect the low pressure side against overpressurization. The valve is set to crack at 160 psi and has a flow capability of 2650 slpm at 310 psi. The projected performance of this valve is shown in figure 29.

D Low Pressure Warning

The low pressure warning is composed of two sections:

(a) Sensing and Actuator Section

(b) Warning Device Section

The Sensing and Actuator Section is made up of two elements. A sensor/transfer valve located in the pressure reducer assembly transfers the outlet pressure from the primary to the backup regulator when the supply pressure drops below 830 psig. The step change in outlet pressure acts on a slide valve incorporated in the mask mounted demand regulator that transfers some of the flow from the spray nozzle through a whistle mounted inside the facepiece.

Consideration was given to use of a single regulator with a separate mechanism to cause an upward step change in outlet pressure. Two schemes are shown in figure 30. Neither of these schemes would contribute to the bypass sytem as does the two regulator concept.

The control element of the sensor/transfer valve should be as large as possible in order to provide maximum sensitivity. However, the resulting pressure balancing spring would be very large and heavy.

Consideration was given to a device (figure 31) wherein air at the original charging pressure is trapped in a cavity and compared with the actual pressure of air in the cylinder. An area ratio mechanism provides the transfer when the cylinder air pressure drops to the preselected value. Heavy springs are not required in this mechanism; however, leakage of the original trapped volume would result in a downward loss in warning time, a situation that is unacceptable.

The design selected for the sensor/transfer valve supplements the load from the pressure balancing spring with the load from a diaphragm acted upon by the outlet pressure from the backup regulator (figure 26). The balanced valve design of the backup regulator keeps this regulated pressure constant.

The proposed low-pressure warning is completely dependent upon the backup regulator. It is imperative that it be functioning properly. (Refer to figure 5).

A press-to-test button incorporated into the cover of the pressure reducer assembly provides for testing the operation of the automatic transfer valve. When depressed, the button prevents the flow of air from the primary regulator (as would be experienced upon a fail closed primary regulator). Continued breathing depletes any primary regulator pressure, thereby the automatic transfer valve opens allowing flow of backup system pressure. Higher backup system pressure will move the slide valve within the breathing regulator such that upon each inhalation, a portion of gas flow is directed through the warning whistle. In this manner, a check for operation of the automatic transfer valve, backup pressure reducer, and warning whistle is readily performed.

The most important functional system check can be performed by the firefighter immediately before entering a hazardous area. By turning off the cylinder valve while slowly breathing on the system or while operating the purge valve, the user can verify the operation of the low pressure warning system and the security of the facepiece seal. Decreased high pressure downstream of the closed cylinder valve will be sensed by the the cylinder actuator. The spring will stroke the valve open and allow flow from the backup regulator to the breathing regulator which will result in low pressure warning upon inhalation as stated above.

Approximately 2 liters of air at 4000 psi would be trapped in the system when the valve is closed. This would allow approximately 4 breaths prior to sounding of the alarm.

Warning Device Section

A whistle mounted in the demand regulator sounds on each inhalation when the backup regulator is activated. The air that powers the whistle is used by the wearer. Tests performed with a whistle mounted inside the face-piece show that the required sound level of 70-90 Db is achieved at the ear with a flow of 6-8 slpm and a pressure of 3-6 inches of water. The same installation resulted in 60-70 Db at a location 12 feet away.

The whistle and the slide valve are shown in figure 23. The slide valve is pushed against a suitable spring by the air in the balance chamber of the demand regulator. When fully switched, some air from the spray bar is diverted to the whistle mounted in the regulator. The back pressure caused by the spray nozzle provides the energy to sound the whistle on each inhalation.

E Cylinder Valve Assembly (figure 32)

The design of the cylinder valve is based on the desire to minimize the length of the cylinder and valve assembly and to minimize the cost of a spare assembly. It is made of an aluminum alloy and coated with a fluorocarbon coating (Teflon "S"). A rectangular rubber bumper is utilized to provide shock absorption for a drop on that end. The valve includes a fusible alloy backed rupture disc and an outward facing gage, arranged so it can be readily read by a "buddy". A formed aluminum gage guard serves as a fitting that mates with the cylinder stop on the backpack frame assembly in order to position the cylinder for connection to the high pressure fitting. The stop is a cantilevered spring arranged to elastically bend to accomodate either of the two sizes of cylinders.

A combination frangible disc-fusible safety device has been selected specifically to protect the Glass Reinforced Plastic (G.R.P.) wrapped compressed air cylinder. High temperature may cause degradation of the outer surface before the internal gas temperature, and hence, pressure rises enough to cause rupture of the conventional unbacked disc. The fusible alloy is selected to melt as a result of the same heat that degrades the vessel. The disc then ruptures at a reduced pressure. Gas is vented through two holes arranged to provide balanced thrust.

The type CG-5 combination frangible disc-fusible plug, utilizing a fusible alloy with yield temperatures not over 220°F, nor less than 208°F, has been selected. A frangible disc designed for 3000 psi service pressure is utilized in the assembly. This disc is designed to burst at 4500 to 5000 psig. Exposure to temperatures over 200°F causes the fusible alloy to melt. As the pressure in the vessel raises to a value between 5000 and 4500 psig, the disc ruptures and safely vents the cylinder. This pressure is considerably below the disc rupture pressure of 6,666 psig that would normally be utilized on a 4000 psi service pressure cylinder. Since the burst pressure of the disc is above the service pressure of the cylinder, short term exposure to heat that may melt the fusible alloy does not result in loss of contents of the vessel with its hazardous impact on the user.

F-

Harness and Frame Assembly

Frame Assembly

Consideration has been given to a molded low density plastic frame assembly (figure 33), a small SCUBA type backpack (figure 34), a thin formed aluminum frame and a composite plastic and aluminum frame.

The small SCUBA backpack, though very light (2.06 lbs.) was judged uncomfortable and it required a band to be attached to each cylinder. The molded low density plastic design could not be made sufficiently flexible to conform to the body shape in the waist and shoulder area, and the hoop type cylinder stop was really only suited to one cylinder size. Aluminum thin enough to provide the desired flexibility for an all aluminum backpack would be susceptible to damage from dropping. The composite plastic and aluminum design was selected, since it provided the desired characteristics at an acceptable cost and weight.

Several different cylinder clamping arrangements were considered as indicated in figure 35 and the first option was selected.

Harness Assembly

Prototype harness and frame assemblies designed and constructed at NASA MSC were the basis for the harness assembly. A contoured, 3-inch wide flexible waist belt connected to the bottom of the frame provides the major support and transfers the weight from the frame to the

hips of the wearer. Adjustable suspender-type shoulder straps hold the frame to the back. Both double and single strap arrangements have been provided for. The waist belt is constructed of neoprene-coated cotton to which is sewn an adjusting tongue of polypropylene webbing. A modified pushbutton automobile seat belt buckle is used for connection and adjustment of the waist belt. The tongue end of the buckle is the front connection point for the single shoulder strap.

Polypropylene webbing has tentatively been selected for the harness due to its good chemical resistance and reasonable cost. Fire resistant grades are available with volume procurement, if the need is subsequently established.

6 SPECIAL DESIGN CONSIDERATIONS

A Spring Design

The specification (FBS-SP-001) requires that the maximum stress on critical parts, such as springs, shall not exceed 50% of the endurance limit. This requirement results in springs that are far larger and heavier than those that are successfully utilized for the same applications at the present time. Regulator springs are successfully exployed at working stress levels of 120,000 psi, whereas a maximum stress of 40,000 psi would be allowed by Item 3.2.11 of Specification FBS-SP-001. In the detail design, good spring design practice has been utilized, as defined by MIL-STD-29A.

B Heat Deflection Temperature

Frame assembly materials specification (3.1.2.3.8 of FBS-SP-001) suggests that the materials have a heat deflection temperature of 300^{O}F (at 264 psi). A preliminary review indicates that the few plastic materials that will meet this criteria have low resistance to chemical attack by commonly encountered chemicals. A heat deflection temperature of 215^{O}F (at 66 psi) has been selected so it will not fall from the user when exposed to higher temperatures.

C Filtration Requirement

A 200 x 200 mesh screen filter has been incorporated in the inlet of the pressure reducer assembly to protect the pressure reducing regulators. The filter provides filtration to 70 microns. No filter or screen has been included in the cylinder valve since the cylinder has an aluminum liner that will not corrode and release particulate contaminants.

D Pressure-Demand Operation

A preliminary study was completed to indicate the advisability of incorporating a pressure demand feature during the design phase. It was determined that the feature could be readily incorporated at a future date. Addition of this feature would have resulted in a program delay of approximately six (6) weeks and a cost increase of approximately $11,000. It was felt that the pressure-demand mode of operation would bypass some of the significant gains in system integrity that would be attained by satisfying the

present specification. Pressure-demand operation would result in an increase in demand regulator weight of approximately one ounce (25 percent) and an increase of $4.00 (17 percent) in manufactured cost. It was recommended that the pressure-demand mode of operation be omitted on this program, since it can be easily incorporated by the manufacturer at a later date, if it is proven desirable.

E Materials

The following is a summary of the materials selected for the various components. Greater detail is provided in the detail drawings.

Facemask

Polycarbonate visor.

60%-40% blend of neoprene and natural rubber in faceseal.

Polypropylene cap assembly with natural rubber band.

Neoprene rubber in oral-nasal cup.

Demand Regulator

Heat-resistant plastic body (G.E. Valox 420 SEO).

Aluminum alloy cover.

Aluminum alloy and Valox 420 valve components.

Cadmium-plated carbon steel springs.

Cotton fabric reinforced reoprene low-pressure hose.

Pressure Reducer

Aluminum alloy body and valve components.

Silicone rubber elastomers.

Cadmium-plated carbon steel springs.

Harness and Frame Assembly

ABS plastic and aluminum frame assembly.

Cadmium-plated steel wire components.

Cotton coated neoprene waist belt with aluminum buckle/adjuster.

Polypropylene shoulder straps.

Cylinder Valve

Teflon "S" coated aluminum alloy, KEL F valve seat.

Nylon plastic knob.

Neoprene bumper.

High Pressure Hose

Double steel wire braid, neoprene core, neoprene covered hose with zinc-plated steel fitting.

Aluminum alloy connection to mate with the cylinder valve outlet.

F **Calculations**

Sample calculations to support the design (flow, stress, etc.) are included in appendix B.

7 SYSTEM PERFORMANCE

A (Original) Projected Performance (As designed)

System weight, system bulk and increased operating duration are factors predominantly controlled by the pressure vessel. However, the significant weight reduction resulting from the use of a high pressure composite cylinder increases the importance of the weight of the other parts of the system.

A maximum weight of 10 pounds is allowed by the Specification FBS-SP-001 excluding the pressure vessel. The sytem, that was a result of the design phase, had an estimated weight of 7.78 pounds as previously detailed. Most of that weight (6.69 lbs. plus the pressure vessel) is carried on a comfortable harness and frame assembly that effectively transfers the weight to the wearer's hips. The remainder of the weight (1.09 lbs.), composed of the facemask, head harness, demand breathing regulator and low pressure hose assembly, is carried by the head.

The unique harness and frame assembly, and lightweight facemask assembly, contribute significantly to the improved human factors of the new system. In addition to the effective transfer of the weight to the wearer's hips, the harness is easy to don and doff, due to the elimination of the chest strap and the use of a quick acting seat belt buckle/adjuster at the waist. Additionally, the harness is designed so that it can be worn with the conventional two shoulder straps, or in a single diagonal strap configuration.

The bubble type facemask is light and small. It is held in place by a net-type head harness and a single adjustable strap. The assembly offers quick don capability and minimizes the problems of helmet/mask interference.

The face seal is the double revert chevron type that has proved effective and reliable.

The demand breathing regulator connects to the facemask through a single large diameter quarter-turn coupling. Good visibility and free head movement result from the assembly. Since the manually operated purge valve is mounted on the side of the demand breathing regulator, it is visible to the wearer and convenient for operation.

The system contains only two manual controls: the previously described purge valve and the cylinder mounted shut-off valve. By reaching back and down with the right hand, the user can easily manipulate the shut-off valve to turn it on for use, or to shut it off to check out the alarm provisions of the system before use. In the unlikely event of failure of the primary pressure reducer in the closed position, automatic transfer to a redundant back-up pressure reducer occurs. This feature eliminates the need for a manually operated bypass.

Improved human factors also result from the increased flow capacity of the system and the interdependence of the depletion warning and the breathing cycle of the user. Two stages of pressure reduction are utilized that yield system flow rates in excess of 535 lpm (BTPS) for supply pressures from 4500 psig to 570 psig at a mask pressure of 2 inches of water negative. Details of the projected system performance are included in figure 36.

It should be realized that the performance characteristics of demand breathing regulators are strongly influenced by somewhat unpredictable factors (O-ring friction, mechanism friction, spring rate of the diaphragm, aerodynamics of the flow passages, etc.); consequently, the design process is as much art as science. Conversely, the performance characteristics of the pressure reducers, that provide output pressures of 90 and 125 psig. are predominantly established by the load spring and the control element. The performance of these devices is more predictable.

The depletion warning operates from the breathing air when the supply pressure is below 830 psig. It provides a signal of 70 to 90 Db at the ear of the user on each inhalation, or continuously if the purge valve is open. A whistle type sound generator is utilized that exhausts the air into the facepiece where it can be breathed by the wearer. By changing the cadence of his breathing, the wearer can differentiate between his warning and that of others who may be nearby. The same warning sound is emitted if there is an unlikely failure of the primary pressure reducer. In either case, the wearer is warned to proceed to a "safe" area.

The system has been designed for a useful life in excess of 10 years or 5,000 use cycles, in fire fighting environments that may range from -60°F to 200°F, assuming that proper, simple maintenance procedures are followed. All design decisions are based on many years experience with similar systems and devices. It is expected that the test program will verify those judgments.

Cost estimates, based on an annual production volume of 10,000 units, indicate a production cost of $125.22. The figure is $5.22 above the $120.00 target and can be traced primarily to the use of a redundant pressure reducer concept in place of a simple manual bypass. However, it is felt that human factors and safety considerations offset the cost factor and result in an acceptable "tradeoff".

B Design Review Action Items

The detail design was presented at a review session at NASA MSC on February 12, 1973. A number of action items resulted from that review as follow:

Recommended Action Items

- Limit the flow capacity of the purge valve on the regulator to approximately 125 to 150 SLPM.
- Consider a position indicating shape or marking for position of that valve.
- Consider a locking device to prevent loosening of low-pressure outlet from the pressure reducer assembly. Also, arrange the hose assembly to fit closer to the pressure reducer assembly.
- Consider alternate energy absorber to replace the wire handle on the bottom of the cylinder valve.
- Provide some restraint on low-pressure hose to prevent looping that might become a snag hazard in use.
- Consider a built-in relief valve or reduce the protrusion.
- Consider a slightly higher location of the cylinder (approximately 2. inches higher)
- Consider a single-piece hose assembly to mate with the modified CGA connector.

- Revise head harness cap to include ear openings.
- Arrange harness assembly to accommodate either the double or single should strap arrangements.
- Revise buckle release to position it more towards the front, and modify it to provide more reliable one-hand release.
- Evaluate a full sling-type harness.
- Consider a change to the regulator stowage pocket on the belt to protect against the ingress of water or other contaminants into the outlet port.

POST DESIGN REVIEW MODIFICATIONS

Consideration of the action items resulted in the following modifications:

- The purge valve was modified to limit its opening by reducing the pitch on the thread and by limiting the rotation of the knob to 180°.
- A position indicating shape was evaluated and, because of the cost impact, it was rejected at this time. It was felt that the same result can be attained by appropriately coloring the knob if it subsequently proves desirable.
- A flange mounted low-pressure outlet fitting has been incorporated that prevents loosening by the action of the hose. It also positions the hose closer to the pressure reducer assembly.
- A rubber bumper has been substituted for the wire handle on the bottom of the cylinder valve. It is more durable and less prone to snagging on objects during use.
- The need for a restraint to prevent looping of the low-pressure hose appears to be alleviated by the redesign of the outlet fitting.
- The relief valve was removed from the top of the pressure reducer assembly and incorporated in the outlet fitting, thereby eliminating the protrustion.
- The cylinder was relocated upward 1½ inches, the maximum amount possible without an upward shift of the pressure reducer.

- A single-piece hose assembly was considered to mate with the modified CGA connector. It was rejected due to the cost impact that results from the need to accurately align the end fittings during the hose/fitting swaging operation. Since one fitting was a 4-bolt flange mount, and the other an elbow, orientation is critical unless a swivel joint or pipe thread is incorporated in the assembly.

- The head harness cap has been modified to include ear openings.

- The harness and frame assembly has been revised so it can be used as a double shoulder strap unit, or a single should strap unit.

- The buckle release has been positioned more towards the front and changed to a pushbutton automotive seat belt type buckle.

- Action on a full sling-type harness has been deferred until the single shoulder strap model has been evaluated.

- The regulator stowage pocket has been changed to a sewn pocket with a flap closure in order to provide protection from the elements.

C ACTUAL PERFORMANCE (FIRST DEVELOPMENTAL MODELS)

The performance of the first developmental models is defined in detail in ER 1041 "Development Test Report" (appendix C) based on procedures defined by ER 1031 "Acceptance Test Procedure" (appendix D) and ER 1027 "Development Test Procedure". The configuration is shown in figure 37. The following is a summary of the essential characteristics.

Human Factors

The human factors considerations of the design phase were established with the aid of a full size mock-up. Consequently, those considerations in the first developmental models were the same as previously reported with the following exceptions:

Weight

The first developmental models had a total weight of 8.18 pounds exclusive of the pressure vessel with the following breakdown:

Facemask and Head Harness	.61 Lbs.
Demand Regulator & Low Pressure Hose Assy	.62 Lbs.
Pressure Reducer Assembly	1.80 Lbs.
Cylinder Valve Assembly	.85 Lbs.
Harness and Frame Assembly	3.50 Lbs.
High Pressure Hose Assembly	.80 Lbs.

Comfort

The developmental model proved to have equal comfort to the (mock-up) prototype fabricated during the design phase. In actual tests with a trained subject, the average time to don the apparatus was 14.5 seconds. Doffing time averaged 1.5 seconds.

Flow Capacity

The flow capacity of the developmental models was slightly below that anticipated by the design phase as detailed in figure 38. Minimum flow occurs immediately prior to the turn-on of the low pressure warning. The maximum flow at that point (approximately 1000 psig) was 506 lpm (B.T.P.S.). Immediately after transfer to the secondary pressure reducer and sounding of the alarm the maximum flow jumps to approximately 700 lpm (B.T.P.S.). The flow values were judged to be satisfactory for the application.

Warning Device

The whistle type warning device on the developmental models actuated at a supply pressure of 850 psig and it provided a signal of 103 DbA at the ear of the user at a frequency of 3570 Hz on each inhalation. The sound appeared to be less noticeable than existing warning systems and it has been left for the field evaluation phase to determine its effectiveness.

Life

A useful life in excess of 5,000 use cycles has been demonstrated by tests. In the operational cycling test, one use cycle was defined as manually opening the valve on the pressure vessel, breathing down a control volume with approximately 10 breathing cycles, causing the alarm to sound for 2 additional breathing cycles, then recharging the control volume and re-closing the cylinder valve.

In other tests the pressure vessel was inserted and removed from the harness and frame assembly 5,000 times, the high pressure connection was made and broken 5,000 times, the low pressure hose to pressure reducer disconnect was mated and separated 1,000 times, and the breathing regulator/facemask connection was mated and separated 5,000 times. During the tests routine maintenance was allowed, however, it was minimal, consisting of replacement of a valve seat in the pressure reducer at 1,000 operational cycles, and tightening of the o-ring retaining screw on the high pressure fitting at 4,500 cycles.

Cost

The cost estimates, based on 1972 rates and on annual production volume of 10,000 units, did not change since the significant details did not change from those of the design phase. It remained at $125.22 per system, a figure that appeared to be acceptable when compared with the $120.00 target cost.

8 SYSTEM DEVELOPMENT (PROBLEMS AND SOLUTIONS)

The development phase consisted of manufacture of three developmental system, acceptance testing of all three systems, and performance of an extensive development test on one system.

During the assembly and test of the developmental systems several minor problems surfaced and were resolved. Seventeen "follow-on systems were then constructed for use in the Field Evaluation Phase. Additional problems surfaced during the Field Evaluation Phase, some of which were corrected and others which were identified for future consideration.

A DEVELOPMENTAL MODEL PROBLEMS AND SOLUTIONS

- Assembly and preliminary testing of the pressure reducer assembly revealed several problems. Leakage occurred at the diaphragm cover interface during burst testing of the low pressure side of the assembly. The condition was corrected by the incorporation of a compression ring to apply a more concentrated squeeze on the diaphragm. The leakage had developed as a result of over-stroking of the diaphragm as the valve was pressed into the relatively soft KEL-F seat by the abnormal pressure loading of the burst test.

- Failure of the diaphragm plate on the low cylinder pressure transfer valve occurred during burst testing of the high pressure side of the pressure reducer. The burst test is conducted with burst pressure on the inlet side but not on the outlet side. Normally inlet pressure acting on an o-ring sealed piston applies a load to the transfer valve that is resisted by a spring and the pressure from the back-up regulator that acts on a diaphragm assembly connected to the valve. The diaphragm assembly included an aluminum plate. Immediately behind the plate, in the pressure reducer cover, is a hole that is connected to the pressure reducer flow passages. The load from the 11,250 psi pressure acting on the piston was sufficient to shear the diaphragm plate, and the shaft connected to the piston was pushed through into the hole behind.

  Follow-up stress analysis showed that the material properties for the plate were marginal. It was changed from aluminum to stainless steel and the assembly passed the subsequent test.

- An intermittent buzzing sound was heard during component testing of the pressure reducer assembly. It was traced to the ball check valve that is between the primary and secondary pressure reducers. Correction was effected by modification of the spring.

- Intermittent effectiveness of the "press to test" system. This system was provided to check the functioning of the back-up regulator and the automatic transfer valve. Investigation revealed that air at indefinite pressure was trapped behind the check valve when the "press to test" was depressed to block the flow from the primary regulator. The trapped pressure acting on the transfer valve caused it to function as a pressure regulator reducing the pressure from the back-up regulator to a lower output pressure. Since the output pressure from the pressure reducer assembly was below that produced by the primary regulator, the whistle alarm would not sound. The transfer valve was redesigned to overcome this tendency to act as a pressure regulator, the pressure reducers were modified, and subsequent testing proved the effectiveness of the modification.

- Initial tests of the demand regulator revealed several problems with the whistle warning device. In order to assure adequate warning at low flow rates, two modifications were required. First, the whistle itself was modified to sound at low flow rates. Second, a backpressure valve was added to the demand regulator assembly in the passage downstream of the whistle, but upstream of the spray nozzle. This valve assures adequate flow to the whistle, even at low flow rates. The extra sensitivity of the whistle required a modification of the slide valve that directs flow to the whistle. In its original form, leakage through the valve, at high demand flow rates, was sufficient to sound the whistle when the valve was not in the alarm mode. A low friction seal was added to the slide valve and it corrected the problem.

- Inward leakage through the exhalation check valve was found to be inconsistent. On two of the the three breathing regulator assemblies values below 1.5 scc/min. were attained. Difficulty in obtaining the required low leakage on the third assembly prompted a review of the tests on the first two assemblies. It was found that the results were not consistently repeatable on those assemblies. The "as produced" valves were capable of repeatably sealing with a maximum leakage of 10 scc/min. By lapping the seats and assembly with extreme care, maximum repeatable values less than 5scc/min. were attainable. By moistening the valve, as usually occurs during use, zero measurable leakage was attained on all three assemblies.

- Higher than expected lock-up pressures were noted on the pressure reducers. The high lock-up pressure on the primary pressure reducer was particularly undesirable since it may result in a false whistle warning. By lapping the valve seat surfaces and utilizing careful assembly techniques, acceptable lock-up characteristics were attained.

- Leakage was experienced during low temperature tests at -65°F. Replacement of the BUNA "N" seals with silicone seals in the low pressure disconnect fitting and relief valve resolved that leakage, however, subsequent testing resulted in leakage at the swaged-on fitting on the high pressure hose. The inner liner of this hose was limited to usage above -40°F and it failed at -65°F. Since high pressure hose capable of withstanding the -65°F service was not available in a timely fashion, it was decided to limit the operational requirements for the system to -40°F.

- The low pressure warning failed to function during the high temperature (200°F) test. Investigation revealed that the regulated pressure of the secondary regulator had dropped from its original setting of 125 psig to 110 psig, which was not enough to actuate the slide valve in the demand regulator; therefore, the whistle did not sound. The pressure shift was found to be caused by stress relaxation of the springs in the pressure reducers. It was corrected by stress relieving the springs in the loaded state. Additional springs were similarly stress relieved and the stability of the load characteristics established. Subsequent testing verified the effectiveness of the procedure.

- The impact shock test resulted in structural failure at two points. First, five of the ten mounting screws, that retain the cover of the pressure reducer, were sheared off. The impact of the drop resulted in rotation of the pressure reducer such that the full load was absorbed by the cover. Analysis and subsequent re-testing resulted in the addition of a protective plate to the side of the pressure reducer to prevent transmission of the load to the cover mounting screws. The second failure occurred during the six-foot drop onto the elbow fitting on the high pressure hose. The outlet fitting of the valve fractured through the vent holes at the juncture of the cone section with the straight section on the modified CGA 1340 connector. Subsequent investigation and further drop testing resulted in the following modifications:

  a) Re-orientation of the grain flow in the valve to run parallel to the axis of the outlet fitting.

  b) Lengthening of the thread on the connector nut so that it reaches further onto the outlet fitting.

  c) Change in the material in the nipple of the connector nut from aluminum to stainless steel.

The facemask leakage tests that were performed on a 16 man test panel revealed performance below that originally specified. Internal leakage tests showed 9 of 16 subjects above the specified 1.5 scc/min. However, 15 of the 16 subjects were better than 3.1 scc/min. In the internal leakage test 5 of 16 subjects exceeded the 200 scc/min. level at 3 inches of water pressure. These leakage values are considerably better than those attainable with currently available facemasks. Consequently, the facemask was judged acceptable.

- Donning and doffing procedures with the facemask revealed that the snaps that connect the net type head harness with the visor were not sufficiently secure and accidental unsnapping was experienced. The problem was corrected by replacement of all of the original snaps with a suitably positioned one way "dot" fasteners. They can only be disconnected by pulling in the direction opposite to that normally experienced during use.

B FIELD EVALUATION MODEL PROBLEMS AND SOLUTIONS

Despite the extensive developmental test program, several urgent problems were uncovered early in the Field Evaluation Phase during manned testing at the Houston Fire Training Academy, and NIOSH certification testing in Morgantown, West Virginia. Other problems emerged as the evaluation program progressed, however, after the half-way mark of the Field Evaluation Program no new problems were reported.

- The first problem to emerge was leakage between the demand regulator and the facepiece. It was detected during certification testing by the National Institute for Occupational Safety and Health (NIOSH) on the 17 field evaluation models. A forming operation was omitted on the sealing grommet in the facemask resulting in insufficient compression of the rubber seal. The acceptance test failed to reveal the deficiency. All systems were subsequently corrected and proven satisfactory by test.

- The second problem to emerge was erratic operation of the warning whistle, and it proved to be a symptom of two different problems as follow:

Premature sounding of the warning whistle, or failure of the warning whistle to turn-off after activation and subsequent release of the press-to-test was the result of an upward shift in the regulated pressures of either or both pressure reducers. The pressure reducing valves were originally configurated as a tubular valve controlled by a spring-loaded fabric-reinforced diaphragm sensing member. The diaphragm was selected for this assembly to minimize the leakage which could be encountered during low temperature testing (-60°F). Because of tolerance requirements for fabrication of the detail parts and because of the flexibility provided by the diaphragm, the tubular valve edge is not guided as precisely as is required to ensure its repeated return to the same position when closing against the valve seat. When the valve is at a lock-up condition (no-flow), the metal edge of the valve impresses into the Kel-F seat material very slightly leaving a "foot print". During use and especially after high flow requirements, a second or even third "foot print" is made caused by misalignment or driven by a unsquare condition of the spring ends. It is the mismatch of the two or more "foot prints" which causes high lock-up pressures because the valve will leak until sufficient outlet pressure is obtained to drive the valve closed into a new but deeper "foot print".

The high lock-up pressure on the primary pressure schedule tends to maintain the slide valve of the breathing regulator in the on position, thus the false warning whistle as previously stated. A high lock-up in the backup pressure reducer acts to maintain the "automatic transfer valve" in the backup pressure mode rather than allowing return to the primary and thus again the false waring whistle. Both of these conditions can be prevented or at least minimized by the control of lock-up pressure to reasonable limits.

A pressure reducer change from diaphragm type to piston type resulted in more repeatable valve-to-seat contact and allowed use of the harder Kel-F 81 seat material. The primary reducer was set to a slightly lower outlet pressure and the backup reducer to a slightly higher outlet pressure to provide greater span for operation of the mask mounted whistle.

The change in the set-points of the primary and back-up pressure reducers necessitated a change in the area ratio of the transfer valve for effective transfer during operation of the press-to-test. At low temperatures (-40°F) performance of this transfer valve was erratic. It was subsequently established that the erratic performance was due to leakage past the check valve that blocks flow back to the primary regulator section of the system. The check valve was redesigned to provide proper low temperature operation.

The most critical failure is that which occurs when the whistle fails to sound. Such a failure was experienced and was subsequently duplicated by long-term exposure of the valve seat in the pressure reducer to high inlet pressure (4500 psi). It has been postulated that a similar failure may result from repeated short-term exposure of the "seat" to high inlet pressure. The mechanism of failure is a hydrodynamic upward extrusion of the seat material that moves the set-point position of the valve-to-seat interface upward thereby decreasing the outlet pressure. At the same time the valve-to-seat "foot print" is increased unbalancing the valve and increasing the outlet pressure at high inlet pressure. Consequently, a check of the outlet pressure at full supply pressure would not necessarily indicate a problem. However, the now unbalanced valve (s) in the pressure reducer (s) yields an output pressure that decreases with inlet pressure. The regulated pressure of the backup pressure reducer that was at 125 psi at 4000 psi supply pressure falls below 110 psi as supply pressure drops to the alarm point (830-880 psi) and this pressure is often not adequate to transfer the slide valve and sound the whistle.

The problem has been corrected by the reconfiguration of the seat as shown in figure 39. The retaining screw prevents cold flow of the Kel-F seat material. The Kel-F seat is fully backed by metal which is also an improvement over the previous design.

The redesigned valve seat with a centrally positioned hold-down screw prevents significant upward movement of the valve seat and minimizes seat extrusion. Failure at the seat, as proven by test, results in an upward pressure shift that sounds the alarm. Only by re-adjusting the outlet pressure after seat deformation has ocurred can a condition be created that would result in lower outlet pressure at the inlet pressure corresponding to alarm actuation.

The modifications were made and extensively tested and the details are reported in ER 1051, "Results of Supplemental Testing Performed on the Modified Firefighter's Breathing System".

- The third problem had been anticipated as a result of comments received from the User Requirements Committee at the pre-field evaluation review. It was suggested that the cover of the demand regulator would not withstand the abuse of service and that debris would enter the slots in the cover and possibly affect performance. Redesign of the cover was immediately begun, however, the field evaluation program was not postponed to

await the modification. Subsequently, the problem did occur in New York, where contamination under the cover prevented proper closure of the exhalation valve and resulted in back leakage into the facepiece. In addition it was found that frequently the cover would rotate when the demand regulator was connected to the facemask. The rotation and subsequent "ramping" of the cover on the inlet fitting often resulted in undesired cover removal.

The cover was redesigned to provide complete protection to both the diaphragm and exhalation valve from foreign probes and/or falling dirt and debris. (figure 40) Exhalation passes through the exhalation valve in the diaphragm and back out towards the chin section of the visor through a protrusion in the lower rim of the cover. Consequently, the cover is unbroken by slots that reduce its strength and that may allow the entrance of dirt or other foreign objects.

The cover is attached by means of a hook on one side and a clip on the opposite. A nylon screw on the bottom rigidizes the connection to prevent accidental removal. A series of tests as defined in detail in ER 1074 (appendix E) were performed to verify the flow capacity and the ruggedness of the new design. Direct impact on the head of the nylon screw during a six foot drop test resulted in fracture of the demand regulator housing. Consequently, a rubber bumper was added to surround the screw head and absorb the energy of the drop. Field evaluation experience subsequently verified the adequacy of the new design.

A fourth, and very evasive problem surfaced during the retrofitting of the field evaluation systems to correct the alarm system malfunctions. The problem was an intermittent squeal in the pressure reducer assembly of some of the systems. It was particularly troublesome for the user, since the frequency was very close to that of the warning device so it was normally accepted as the warning tone. The intermittent nature of the squeal made diagnosis of the problem particularly difficult.

The problem was subsequently diagnosed as resonant cavity amplification of a specific frequency of the random noise generated at the valve seat of the pressure reducer. It was resolved by insertion of a pin of suitable size into the resonant cavity (upper part of the piston), in order to create a mixed boundary condition to upset the resonance.

Analysis was begun by measurement of the frequency of the squeal. It was found to be essentially a pure tone at 3000 Hz., which was very close to the warning whistle tone of 3100 Hz.

The source of the squeal was positively established as the pressure reducer, rather than check valve or transfer valves, by the construction of a single function pressure reducer that exhibited the same intermittent squeal problem as the complete pressure reducer assembly. It was found that the squeal was most repeatedly generated with a new valve and seat with the regulator at a high ambient temperature. Longitudinal vibration of the piston acting against the regulator spring, as a simple mass spring system, was dismissed when the natural frequency was computed to be 149 Hz., far below the measured frequency of the squeal.

A higher frequency longitudinal vibration resulting from the high spring rate of non-sliding o-rings was investigated by replacement of the o-rings with lower friction quad ring seals and also with a spring loaded T.F.E. seal. Neither modification permanently changed the characteristics of the squeal.

Lateral vibration of the piston stem was considered a possibility. The guiding of the piston stem was improved with no effect. Subsequently, friction damping in the form of T.F.E. plugs that squeezed the stem proved equally ineffective. Consequently, lateral vibration of the stem was eliminated as a probable cause of the squeal.

Consideration of the "organ pipe" effect of the central bore of the piston proved significant. Analysis showed that the fundamental frequency of the bore acting as a closed pipe was 3036 Hz., which was essentially the value of the squeal.

In order to prove the theory and to remedy the problem, several modifications were attempted. First, a spring was inserted in bore of the piston, but that proved ineffective. Next, the cover of the regulator was modified so a screw could be inserted to penetrate into the bore of the piston, without touching the piston itself. By insertion and removal of the screw it proved possible to repeatedly eliminate the squeal. The theory had been proven and one possible remedy found.

The insertion of a screw through the cover was not considered a good final remedy, since that design created a possible leakage path from the pressure reducer. Subsequently, it was found that a Kel-F 81 pin inserted in the outlet end of the piston (figure 41) repeatedly silenced the squeal. The pin created a mixed boundary condition at the outlet of the resonant cavity with the pin promoting "closed pipe" resonance at approximately 3000 Hz. and the space around it promoting "open pipe" resonance at approximately 6000 Hz. The net effect was total elimination of the squeal.

A more detailed analysis is included in ER 1073 "Investigation and Correction of Pressure Reducer Squeal on the Firefighter's Breathing System".(appendix F)

Subsequent qualification testing as reported in ER 1064 "Delta Qualification Test Report of the Pressure Reducer Sonic Alternator for the Firefighter's Breathing System" (appendix G) and Field Evaluation experience proved the effectiveness of the modification.

Final system performance is defined in detail in ER 1056 "Delta Qualification Test Report for the Modified Firefighter's Breathing System" (appendix H) and graphically in figure 43.

- The fifth problem to emerge was the first significant problem to show up during actual field usage. It was a seal failure on the "banjo type" inlet fitting on the demand regulator. The retaining ring that holds the fitting in place was found to be too weak. Failure of this ring resulted in outward movement of the fitting that led to extrusion of the inner o-ring seal and significant and unmistakenly audible leakage. Substitution of a stronger retaining ring resulted in positive retention. Retrofit was accomplished on all field evaluation system, and the subsequent usage verified the effectiveness of the corrective action.

- The sixth problem was the result of slight differences in functionally significant physical dimensions of the new demand regulator cover over those of the original design. Following retrofit of the cover on the field evaluation models, some of the exhalation valves were found to buzz during exhalation. Additional clearance between the diaphragm and the cover allowed the diaphgram to stretch like a banjo skin, and to amplify the normally minor flutter of the exhalation valve. The buzzing was corrected by increasing the thickness of the retaining button on top of the exhalation valve.

At the same time it was discovered that, with the cover removed, the actuating lever for the demand valve could move over center to prevent operation of the valve. A longer actuating arm on the lever eliminated this problem. All field evaluation models were refitted with the revised lever.

- The need for a leak tight fit between the demand regulator and the facepiece resulted in several complaints about the high force required to make the connection. Routine cleaning and lubrication of the rubber seal on the face-piece proved effective in minimizing the problem during the field evaluation. However, a redesign of this interface seal is indicated for follow-on production models.

- Inadvertent rotation of the purge valve on the demand regulator, with the resultant free flow of air, was a "sometimes" nuisance problem. Consideration of a position indicator on the knob, and of modification of the mechanism to provide a "lock-out" feature has been suggested for future models. A push-to-actuate "lockout" was considered but rejected because of the greater hazard it created. By pushing on the valve to overrride the lock-out the user may "break" his faceseal with resultant inboard leakage. Free flow through the inadvertently opened purge valve is at least a safe condition that is simply resolved by manually closing the valve.

- Under some conditions internal mask fogging has occurred. The demand regulator is designed to spray the major portion of the inhalation flow over the visor. However, the mechanism is such that some of the flow leaks through the valve lever port into the facemask without passing over the visor. Figure 42 shows that the percentage of flow leaking around the spray nozzle is greater at low flow rates than at high flow rates. Field experience indicated that the mask fogging generally occurred at low work rates in cool ambient conditions.

  Improved sealing of the valve lever port is not practical since it would degrade the present easy breathing characteristics of the demand regulator. The design, in its present form, is superior to existing systems. Through the use of anti-fog compounds and by judicious use of the purge valve the infrequent problem of fogging of the facepiece can be accomodated as proven by the field evaluation experience.

9 FINALIZED SYSTEM

A Configuration

Except for the shape of the cover on the mask mounted demand regulator, the finalized system appears the same as that of the developmental models as shown by comparing figure 43 with figure 37.

B Performance

All human factors considerations of the developmental models were retained in the finalized design.

The flow capacity of the finalized system is slightly less than that of the developmental models as shown by comparing figure 44 with figure 38. However, the reduced flow capacity has been found more than adequate and alarm system reliability has been enhanced.

The useful life of the finalized system was proven by test to be in excess of 5,000 use cycles.

C Cost

The finalized cost estimates, based on 1972 rates and an annual production volume of 10,000 units remained the same since there were no significant changes from the design phase. It remains at $125.22 per system, or $5.22 above the original target cost.

10 CONCLUSIONS

A new open circuit, compressed air Firefighter's Breathing System has been designed and developed that provides reduced weight, greater comfort, improved human factors design, improved breathing regulator performance and an improved low-pressure warning system.

Combined with either of two lightweight pressure vessels developed by NASA on separate contracts, the following system weights result:

1. System with 40 standard cubic feet of air, 19.8 pounds fully charged for use.

2. System with 60 standard cubic feet of air, 24.8 pounds fully charged.

Compared with the currently available breathing systems that provide 45 standard cubic feet of air and weigh approximately 33 pounds, the following features are included:

1. Smaller, lighter backpack mounted cylinder and valve assembly.

2. Compact, comfortable, harness and frame assembly that effectively transfer the weight of the cylinder assembly to the wearer's hips. It is configured so it can be used with either single or a double shoulder strap. The band-type cylinder clamp and valve mounted lower stop allow bottom installation for faster cylinder changes during use.

3. A small, lightweight facemask with a unique head harness that fits beneath the fireman's hat without impairing the fit or requiring that the head band be adjusted. The mask has a large quick-connect fitting to mate with the breathing regulator. When the regulator is removed, the fireman can readily breathe through the opening.

4. A mask-mounted demand-type breathing regulator incorporating the exhalation valve, a purge valve and a whistle-type low pressure warning that sounds only during inhalation.

5. A frame mounted pressure reducer assembly that includes two pressure reducers, an automatic transfer valve and a signaling device for the low pressure warning. A bypass valve is not included; instead, a backup pressure

reducer activated by a transfer valve automatically takes over if the primary pressure reducer fails closed. Whenever the secondary pressure reducer is in operation, the warning whistle sounds on each inhalation. The warning signal is the same for pressure reducer failure and for low cylinder pressure, but in either case the fireman must immediately move to a "safe" area.

The system manufacturing cost exclusive of the pressure vessel is approximately the same as existing systems. However, new product "start-up" costs and capitalization costs of new tooling may result in slightly higher selling prices.

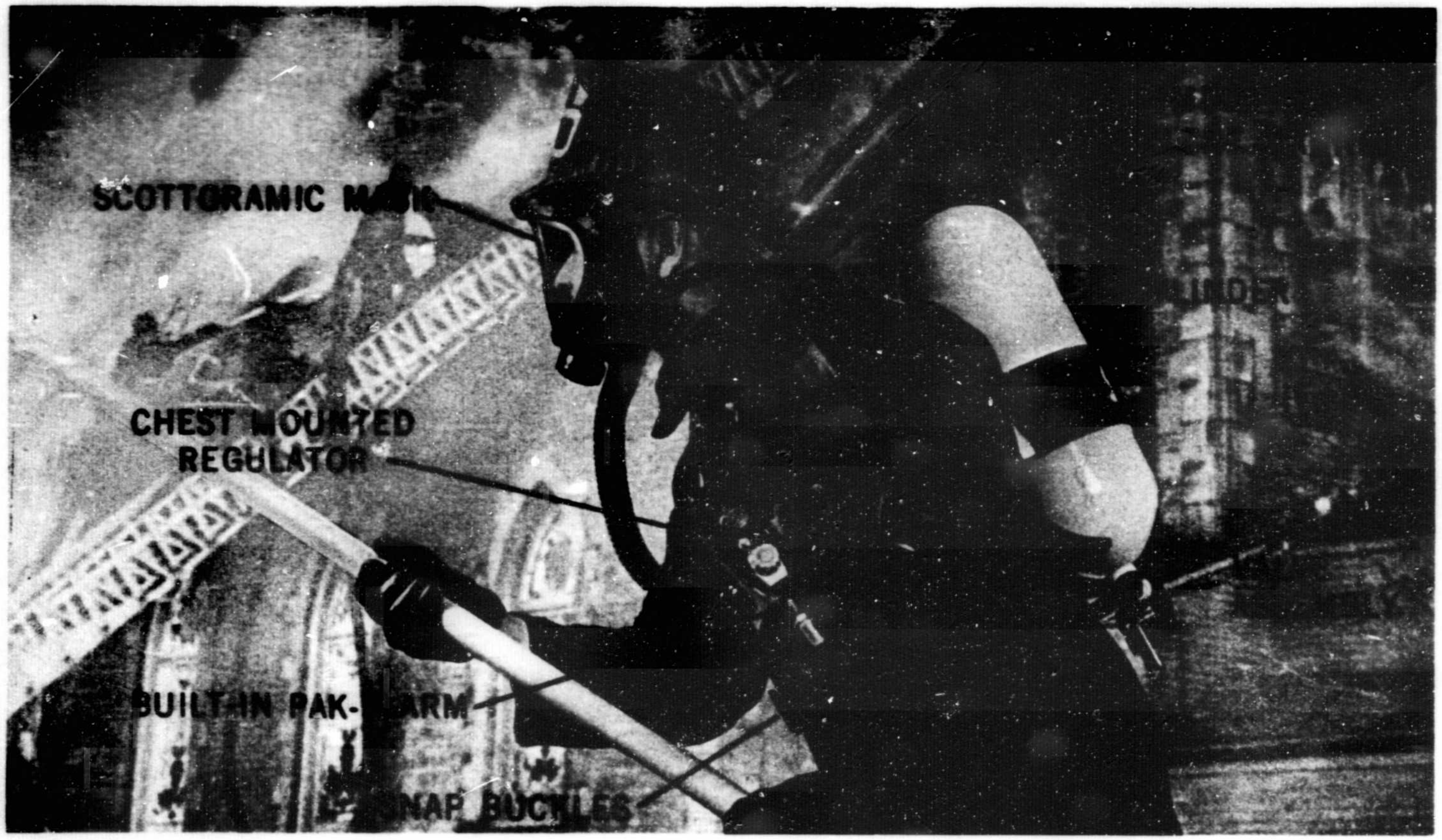

SCOTTORAMIC MASK
CHEST MOUNTED
REGULATOR
BUILT-IN PAK-ALARM
SNAP BUCKLES

Fig. I

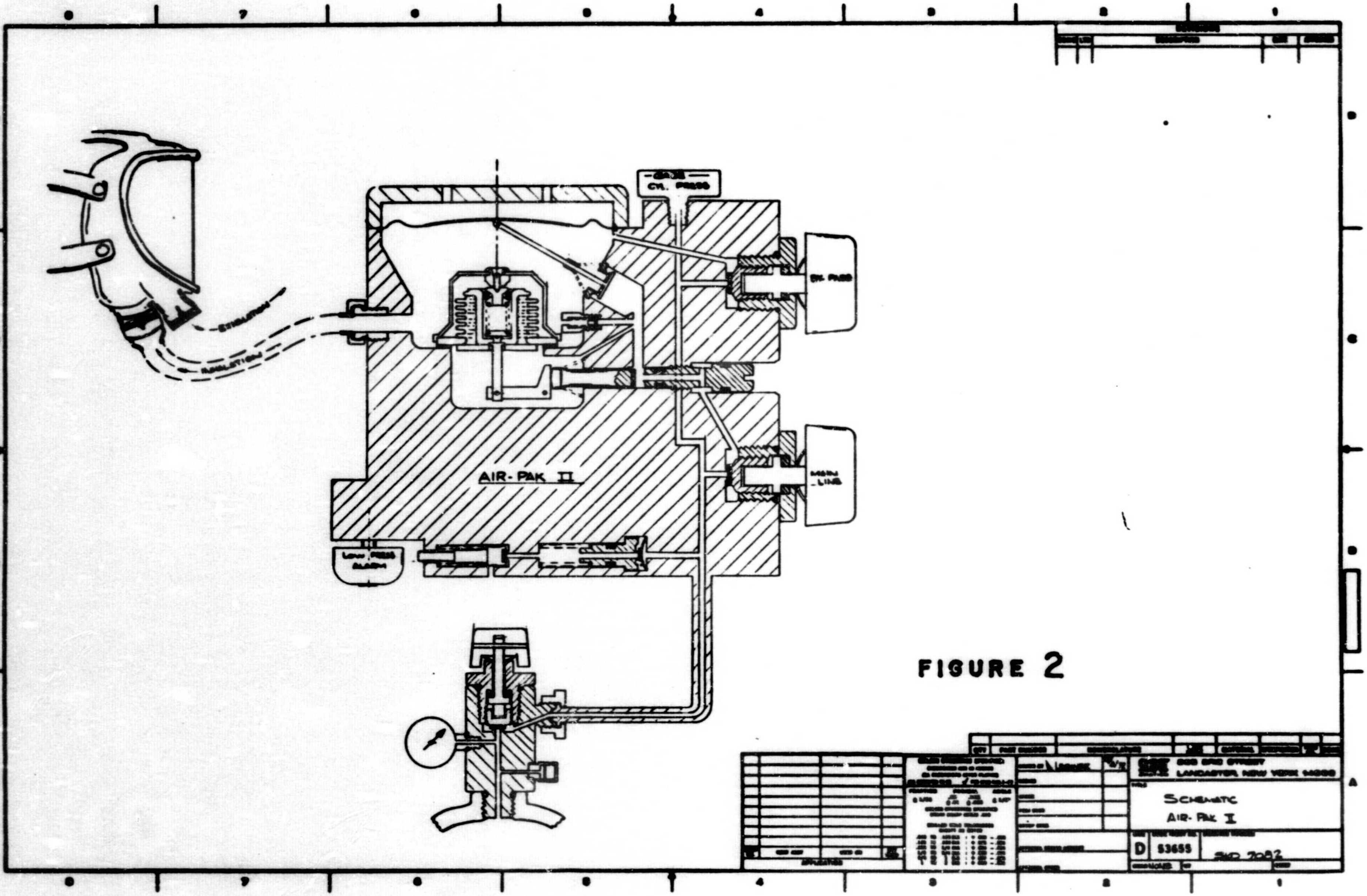

CYL. PRESS
AIR-PAK II
MAIN LINE
LOW PRESS ALARM
LANCASTER, NEW YORK
SCHEMATIC
AIR-PAK II
D
53655
SKD 7082

FIGURE 2

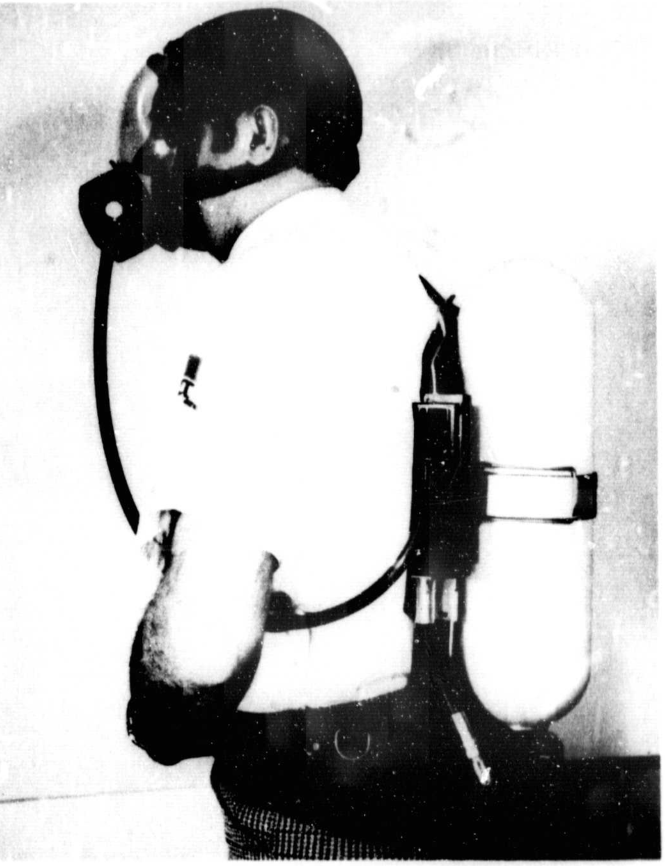


FIGURE 3

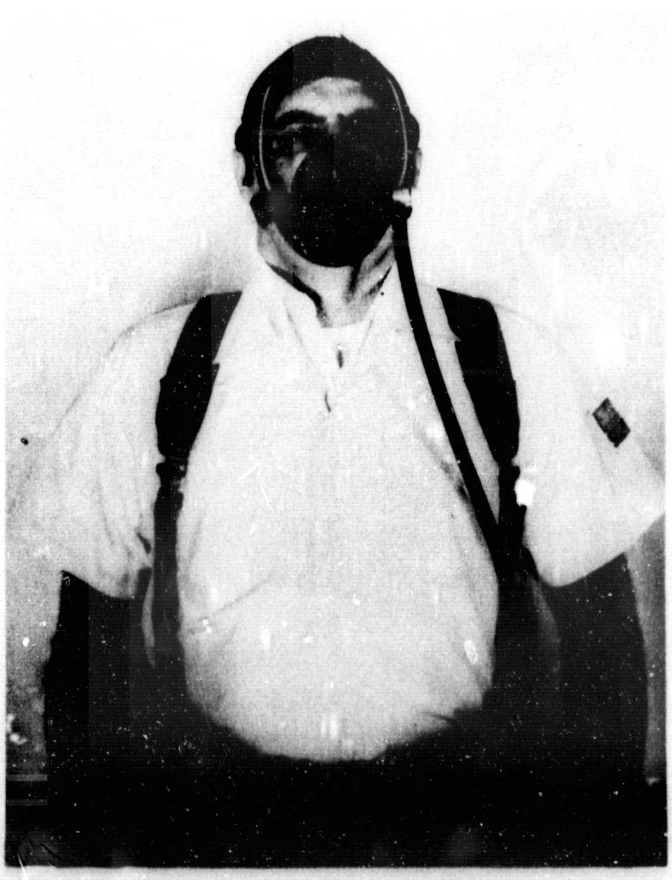


FIGURE 4

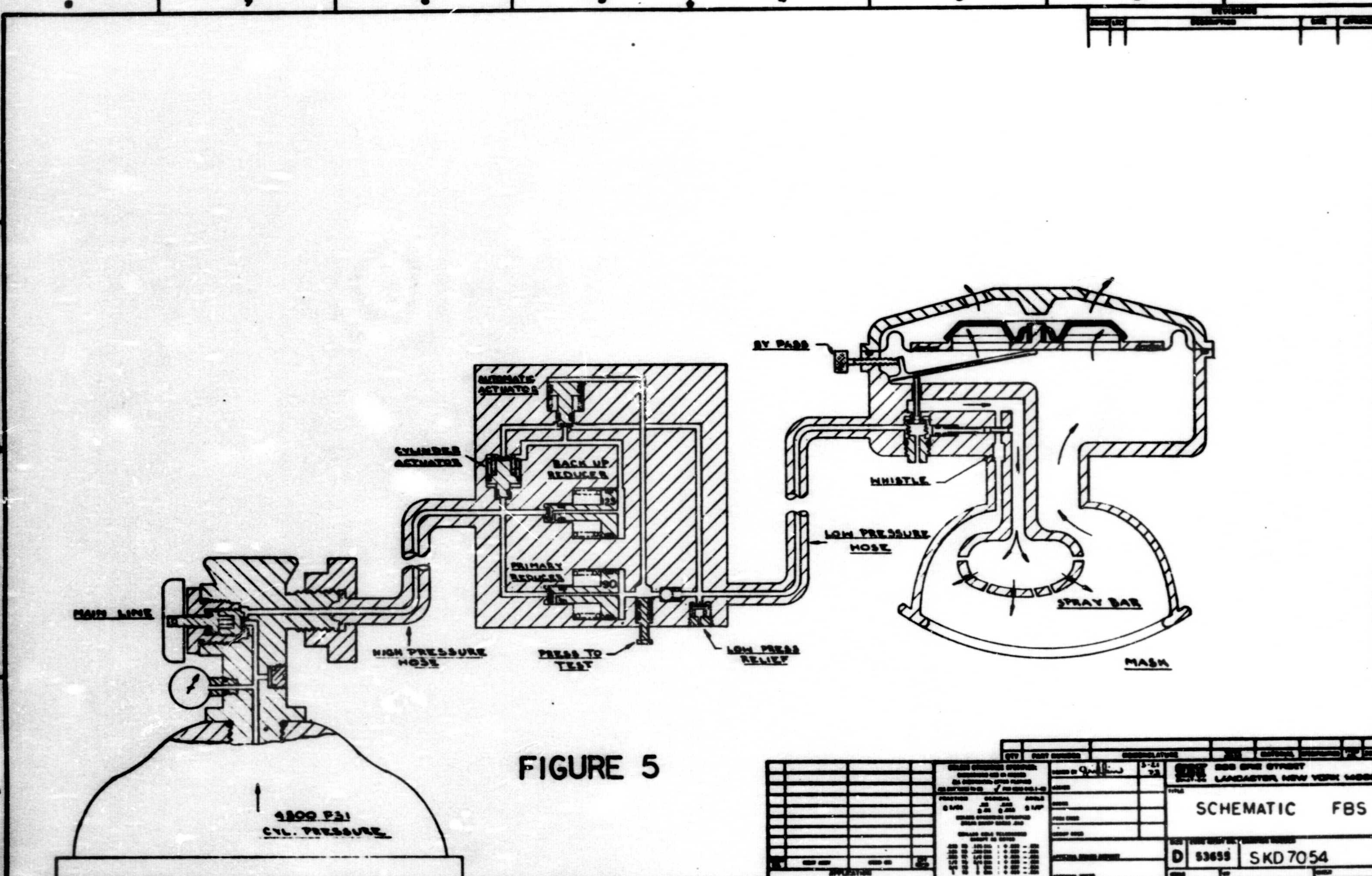
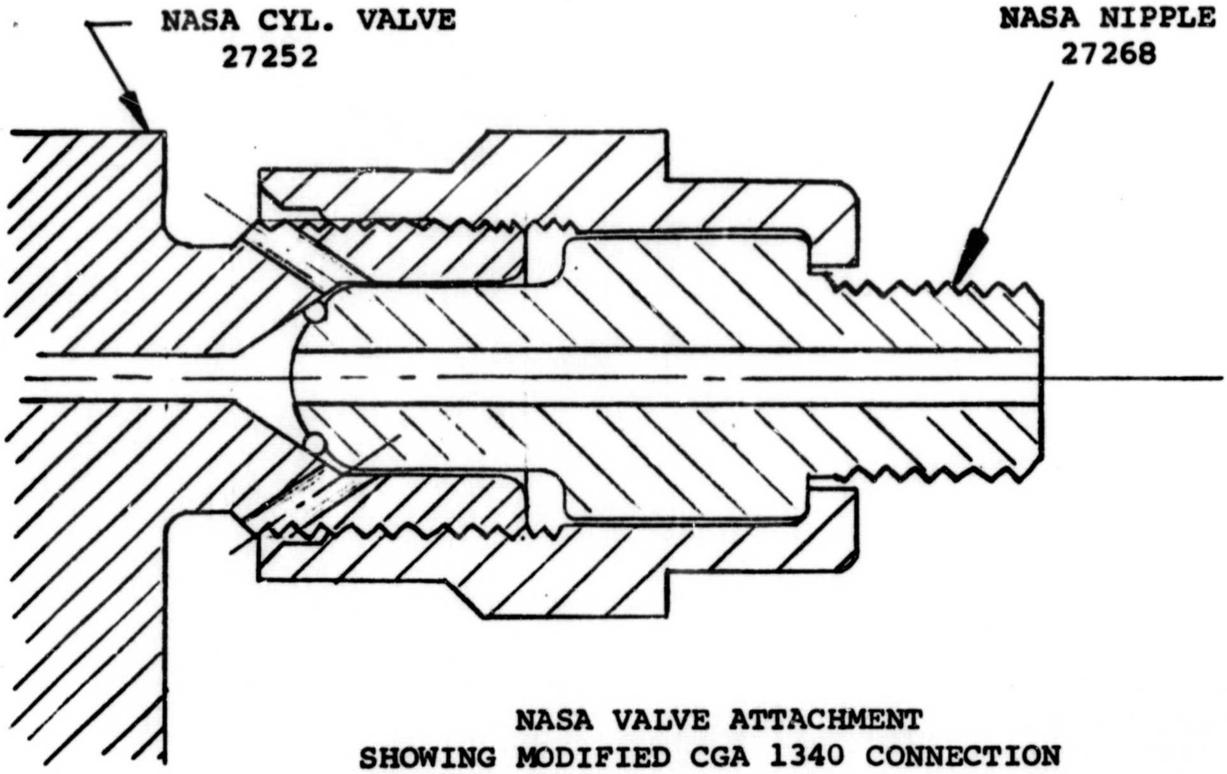
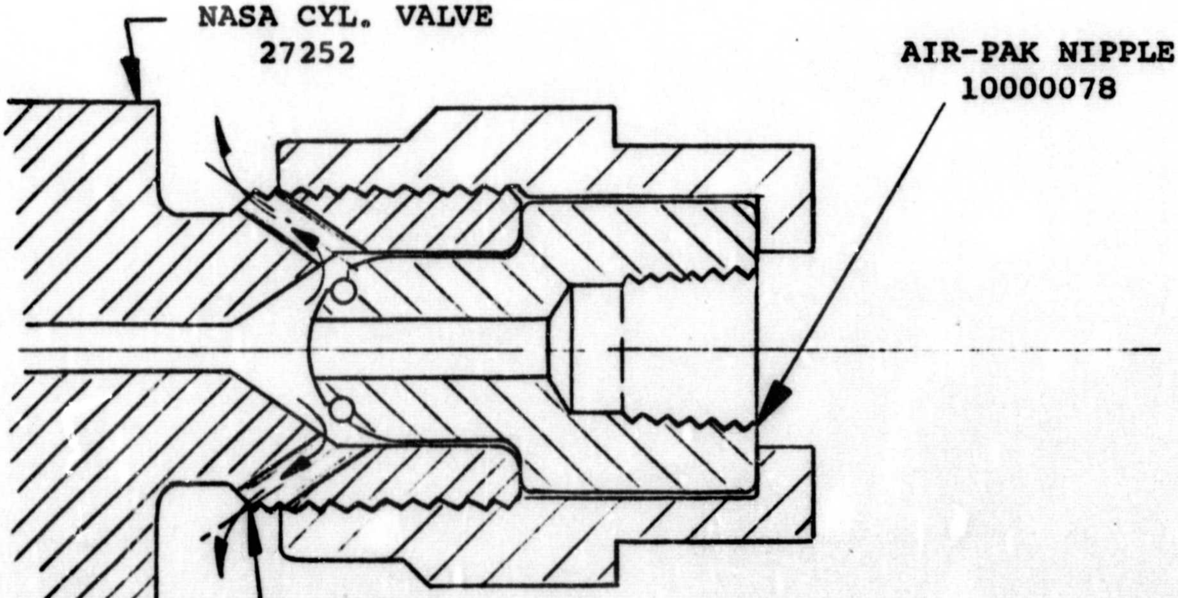

AUTOMATIC ACTUATOR
CYLINDER ACTUATOR
BACK UP REDUCER
PRIMARY REDUCER
BY PASS
WHISTLE
LOW PRESSURE HOSE
SPRAY BAR
MASK
MAIN LINE
HIGH PRESSURE HOSE
PRESS TO TEST
LOW PRESS RELIEF
4500 PSI CYL. PRESSURE
SCHEMATIC FBS
D
53655
SKD 7054

FIGURE 5



NASA VALVE ATTACHMENT
SHOWING MODIFIED CGA 1340 CONNECTION



NASA VALVE WITH SCOTT AIR-PAK
AND NUT CONNECTED. CGA 1340 WILL
FIT THE SAME.

MODIFIED CGA 1340 CONNECTION
Figure 6

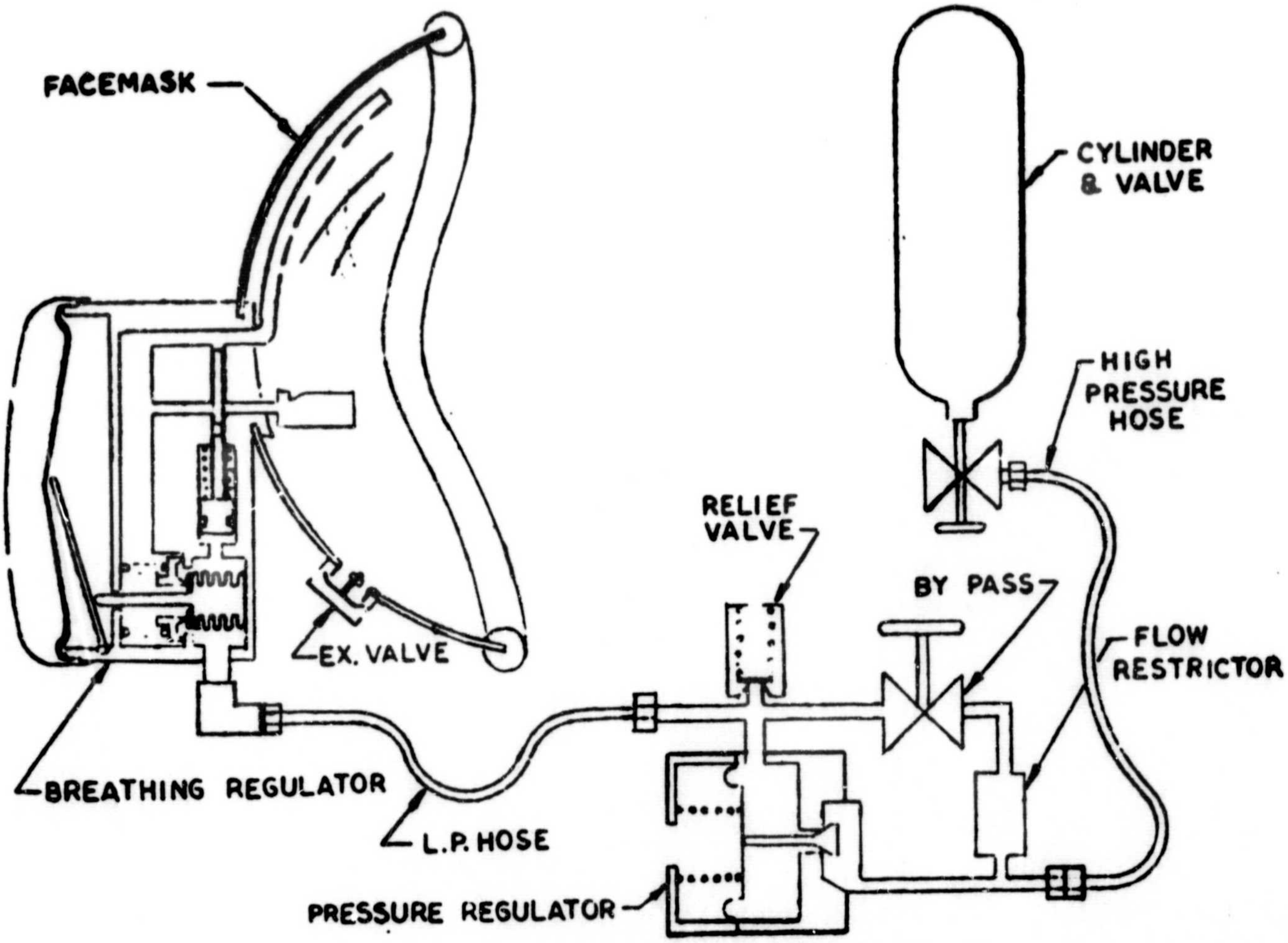
SYSTEM ANALYSIS CHART

System	Advantages	Disadvantages
A Refer to Fig. 8 Cost $107.47 Weight 7.37 lbs.	Simple design concepts use of standard parts. Minimum parts and adjustment requirements. Low Pressure warning would occur on by-pass	Cylinder pressure (830-880) may not be sensed and referenced to breathing reg. reliably. By-pass valve may be inaccessable. Flow restrictor not feasible, requires press. reg. to limit flow. Large diameter hose required to pass flow at 30 psig regulated pressure. Large diameter valve size in breathing regulator required. Integral relief in breathing reg. complicates design. Actuation of L. P. warning not predictable.
B Refer to Fig. 9 Cost $114.48 Weight 7.52 lbs.	Balanced valves accomplish flat outlet press. schedule with minimum cost and simplicity. Low outlet pressure (30 psig) increased from System A Cylinder pressure sensing actuator allows reliable signal to breathing regulator. Reduced hose diameter from first stage to breathing regulator. Improved valve size condition compared to System A Low pressure warning improved over System A	Balanced valve design slightly more complex. Method required to increase outlet pressure complicates basic first stage regulator design. Separate regulator may be required to prevent external leakage, continuous bleeds, By-pass valve may be inaccessable. Flow restrictor not feasible requires pressure regulator to limit flow. Integral relief valve in breathing regulator complicates design.
C Refer to Fig. 10 Cost $106.47 Weight 7.49 lbs.	Valve design in breathing regulator least complex. High spray bar pressures capable without affecting valve stability. Other comments the same as "B" above.	cracking force greatest requiring largest diaphragm in breathing regulator. Other comments the same as "B" above.
D Refer to Fig. 11 Cost $107.50 Weight 7.37 lbs.	Reduced facemask complexity and maintenance. Other comments the same as "A" above.	Overall thickness of breathing regulator increased to provide stroke for exhalation. Breathing regulator more complex. Other comments the same as "A" above.
E Refer to Fig. 12 Cost $114.47 Weight 7.52 lbs.	Reduced facemask complexity and maintenance. Other comments the same as "B" above.	Overall thickness of breathing regulator increased to provide stroke for exhalation. Other comments the same as "B" above.
F Refer to Fig. 13 Cost $110.54 Weight 8.09 lbs.	Minimum weight attachment at facemask. Other comments the same as "A" above.	Low Pressure breathing tube from chest mounted regulator to facemask adds weight penalty. Difficulty in transmitting audible warning signal thru breathing tube. Coaxial breathing tube required for remote sensing and spray bar delivery.

FIGURE 7

System	Advantages	Disadvantages
F (con't)		Breathing tube pressure can be below ambien pressure therefore increasing risk of inboard leakage through more sealing areas. Other comments the same as "A" above.
G Refer to Fig. 14 Cost $117.29 Weight 8.24 lbs.	Minimum weight attachment at facemask. Other comments the same as "B" above.	Low pressure breathing tube from chest mounted regulator to facemask adds weight penalty. Difficulty in transmitting audible warning signal thru breathing tube. Coaxial breathing tube required for remote sensing and spray bar delivery. Breathing tube pressure can be below ambie: pressure therefore increasing risk of inboard leakage thru more sealing areas. Other comments the same as "B" above.
~~H~~ ~~Refer to Fig. 15~~ ~~Cost $63.44~~ ~~Weight 6.08 lbs.~~	~~Minimum weight.~~ ~~Fewest parts and components.~~ ~~Least expensive.~~ DOES NOT SATISFY SPECIFICATIONS	~~Combination cylinder valve and regulator increases spare cylinder costs.~~ ~~Failed closed first stage regulator results in complete loss of breathing. air.~~ ~~No low pressure warning provisions.~~ ~~Large first stage outlet pressure variation from high to low cylinder pressure.~~ ~~Variable cracking force (High to Low) proportional to first stage regulator pressur~~
J Refer to Fig. 5 Cost $126.67 Weight 7.92 lbs.	Use of proven design components. Redundant pressure regulation (first stage) By-pass control knob readily accessible. Accurate cylinder sensing actuator for low pressure warning. Balanced valves in first stage and breathing regulator provide minimum cracking and breathing resistance Failed closed first stage regulator will be automatically switched to the back-up low pressure warning will be transmitted. All functions of inhalation, exhalation, by-pass and low pressure warning signal incorporated in breathing regulator; facemask least complex. Requirement for coaxial breathing tube eliminated. Inboard leak paths at a minimum. Flow thru audible warning is consumed not vented to ambient.	Automatic switching from primary pressure regulator to back-up pressure regulator requires more component parts and slight weight increase in the manifold. Moderate weight attachment at facemask. Failure closed of back-up regulator results in no low pressure warning. No automatic check out of low pressure warning on turn-on; Manual check out procedure required.

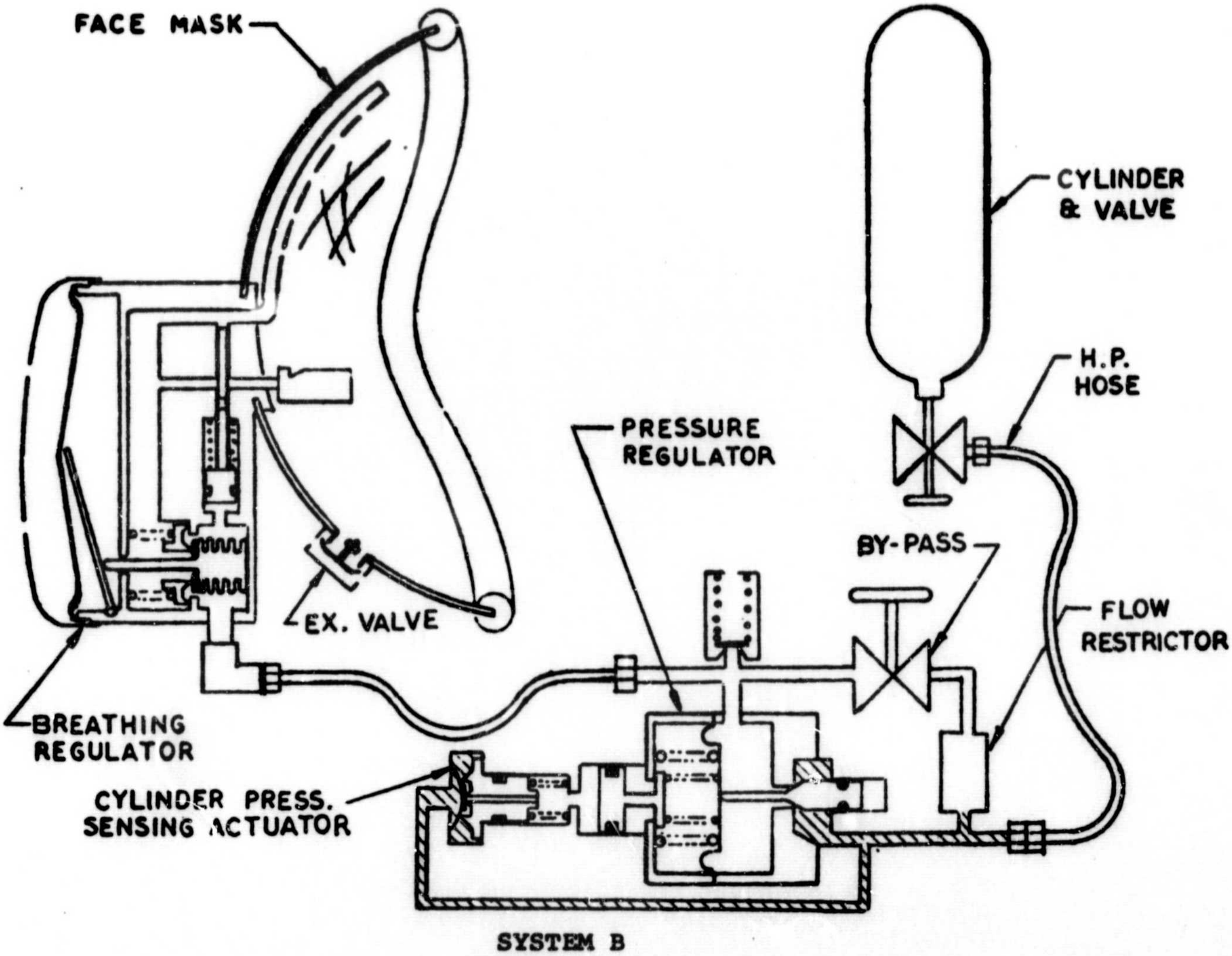
FIGURE 8



SYSTEM A

1. Harness, frame, cylinder & valve
2. Pressure regulator (1st stage)
   - back mounted, upstream valve
   - regulated pressure, 30 to 110 psig
   - pressure span to actuate low pressure warning
3. By-Pass
   - back mounted, manual high pressure valve
   - flow limited by restrictor
4. Hose
   - pressure regulator to breathing regulator
5. Breathing Regulator
   - mask mounted
   - balanced upstream valve
   - remote sensing
   - integral relief valve
   - low pressure warning
6. Facemask
   - Scottovista
   - exhalation valve

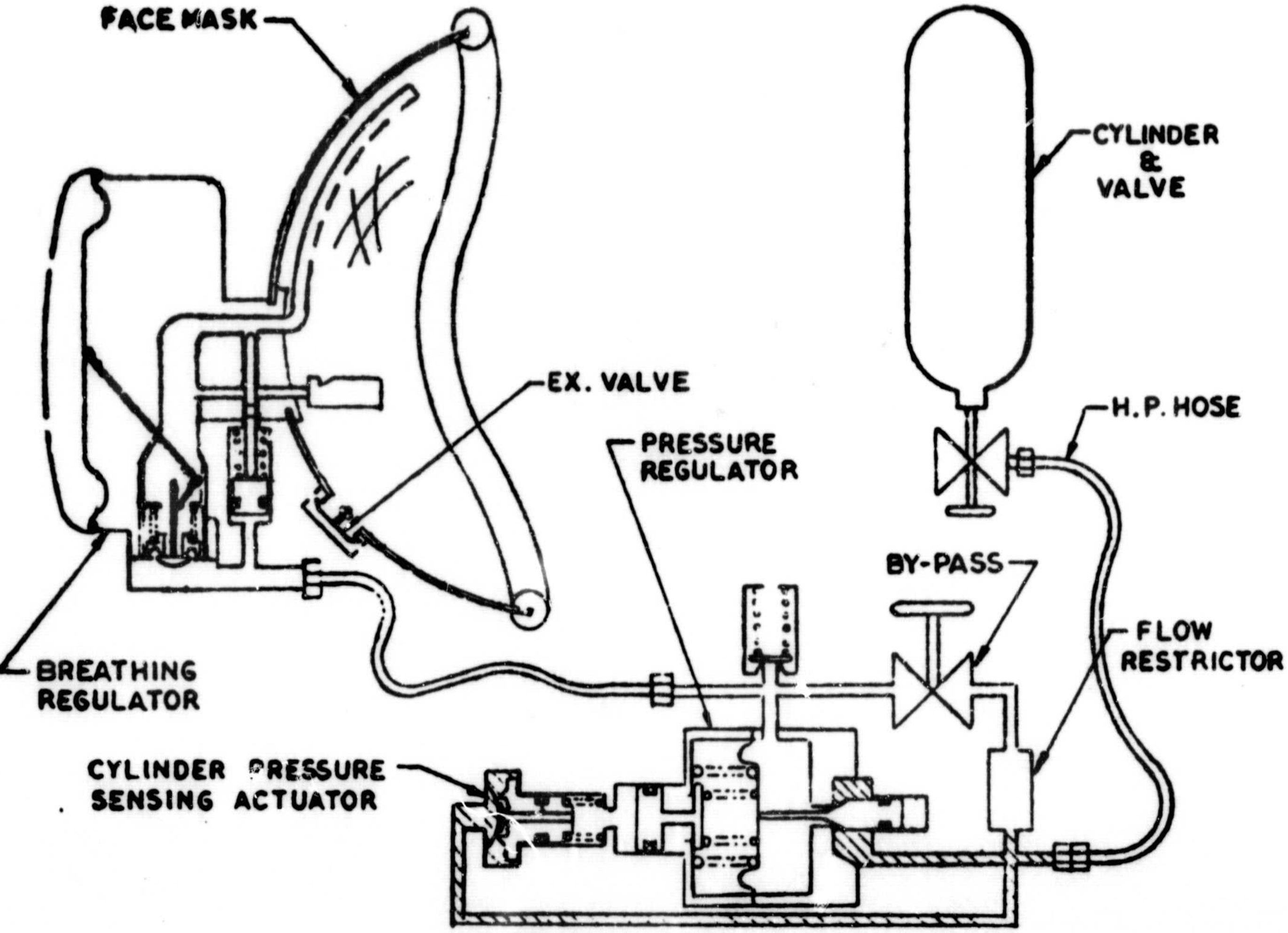
Fig. 9



SYSTEM B

1. Harness, frame, cylinder & valve
2. Pressure regulator (1st stage)
   back mounted single stage
   balanced upstream or downstream valve
   or flat outlet pressure schedule
   cylinder pressure sensing-actuator to increase outlet
   pressure to control low pressure warning.
3. By-Pass
   back mounted, manual high pressure valve
   flow limited by restrictor
4. Hose
   Pressure regulator to breathing regulator
5. Breathing regulator
   mask mounted
   balanced upstream valve
   remote sensing
   integral relief valve
   low pressure warning
6. Facemask
   Scottovista
   exhalation valve

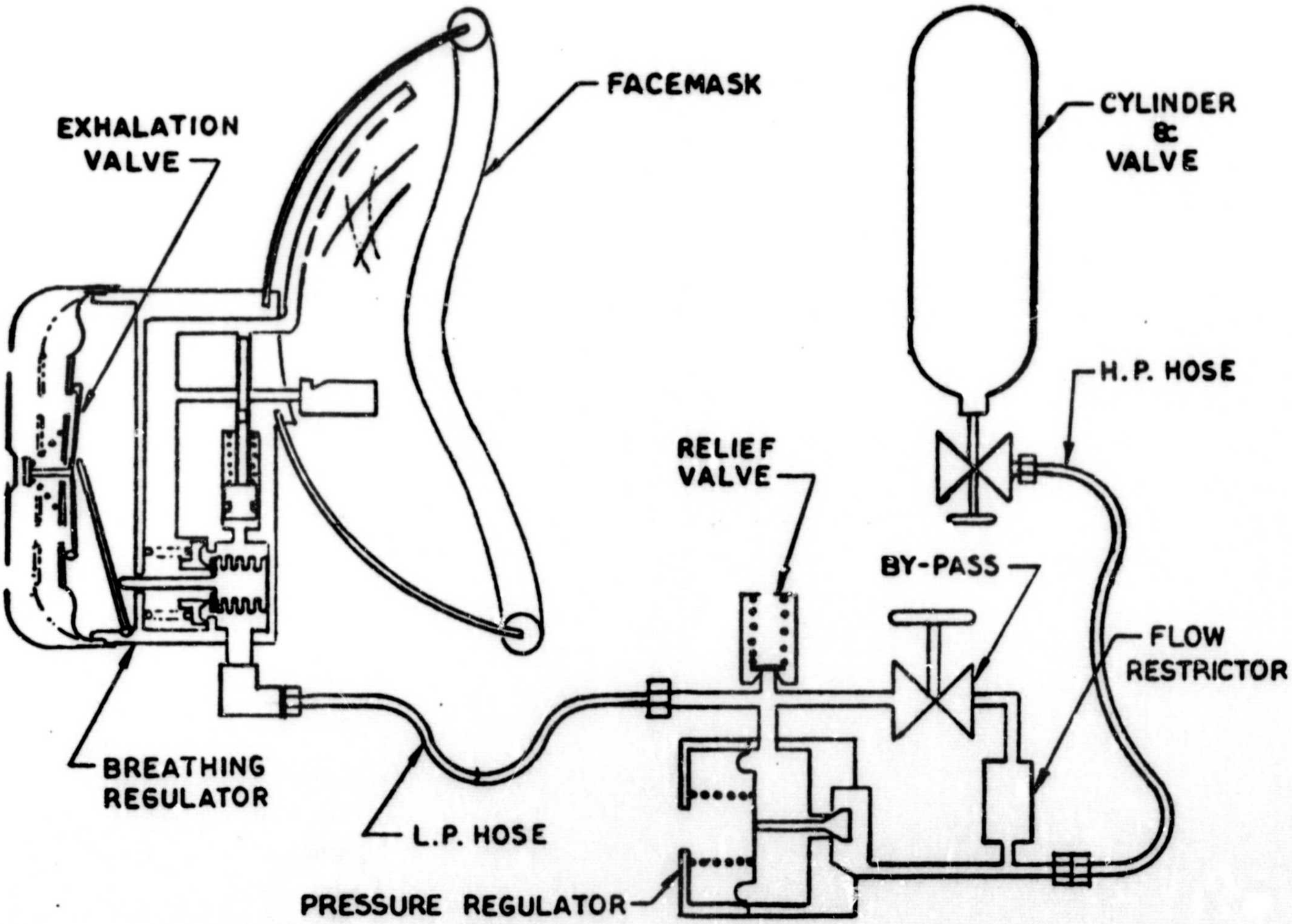
Fig. 10



SYSTEM C

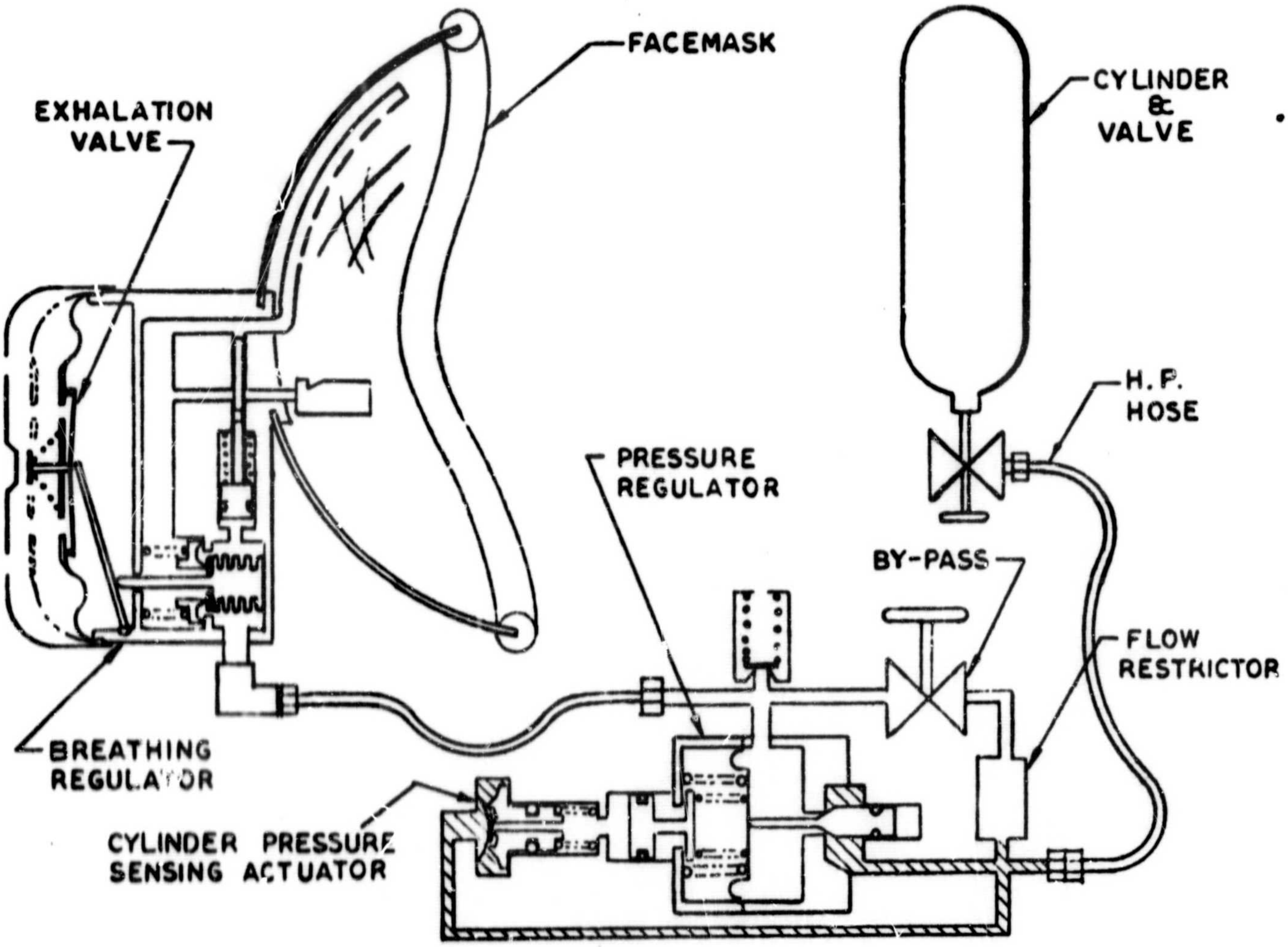
1. Harness, frame, cylinder & valve
2. Pressure regulator (1st stage)
   - Back mounted, single stage
   - Flat outlet pressure schedule or balanced upstream or downstream valve
   - Cylinder pressure sensing-actuator to increase outlet pressure to control low pressure warning.
3. By-Pass
   - Back mounted, manual high pressure valve
   - Flow limited by flow restrictor
4. Hose
   - Pressure regulator to breathing regulator
5. Breathing regulator
   - Mask mounted
   - Onbalanced valve
   - Remote sensing
   - Integral relief valve
   - Low pressure warning
6. Facemask
   - Scottovista
   - exhalation valve

Fig. 11



SYSTEM D

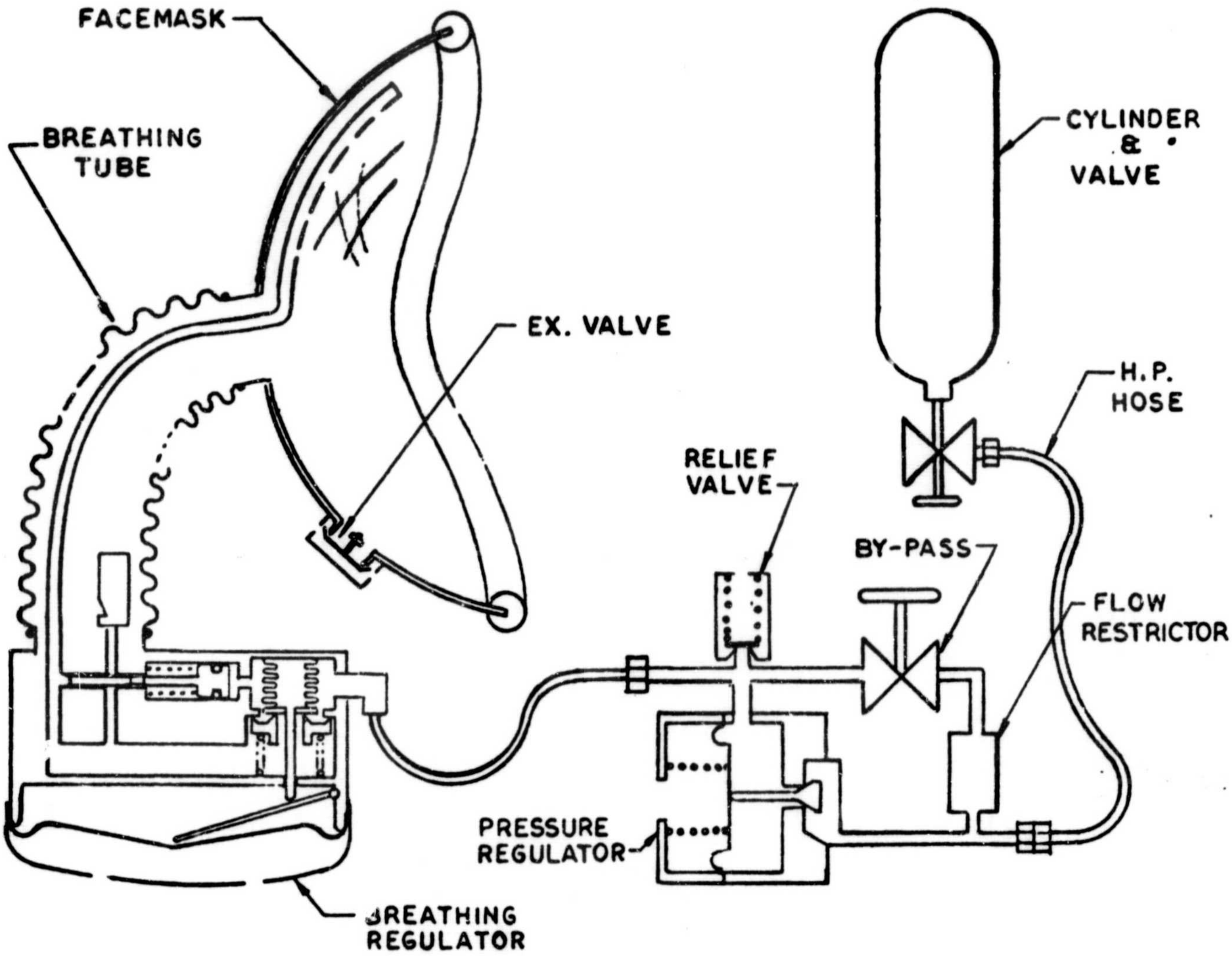
System identical to that shown in Fig. 9 , except that exhalation valve is incorporated into diaphragm of breathing regulator.



System E

System identical to that shown in Fig. 10, except that exhalation valve is incorporated into diaphragm of breathing regulator.

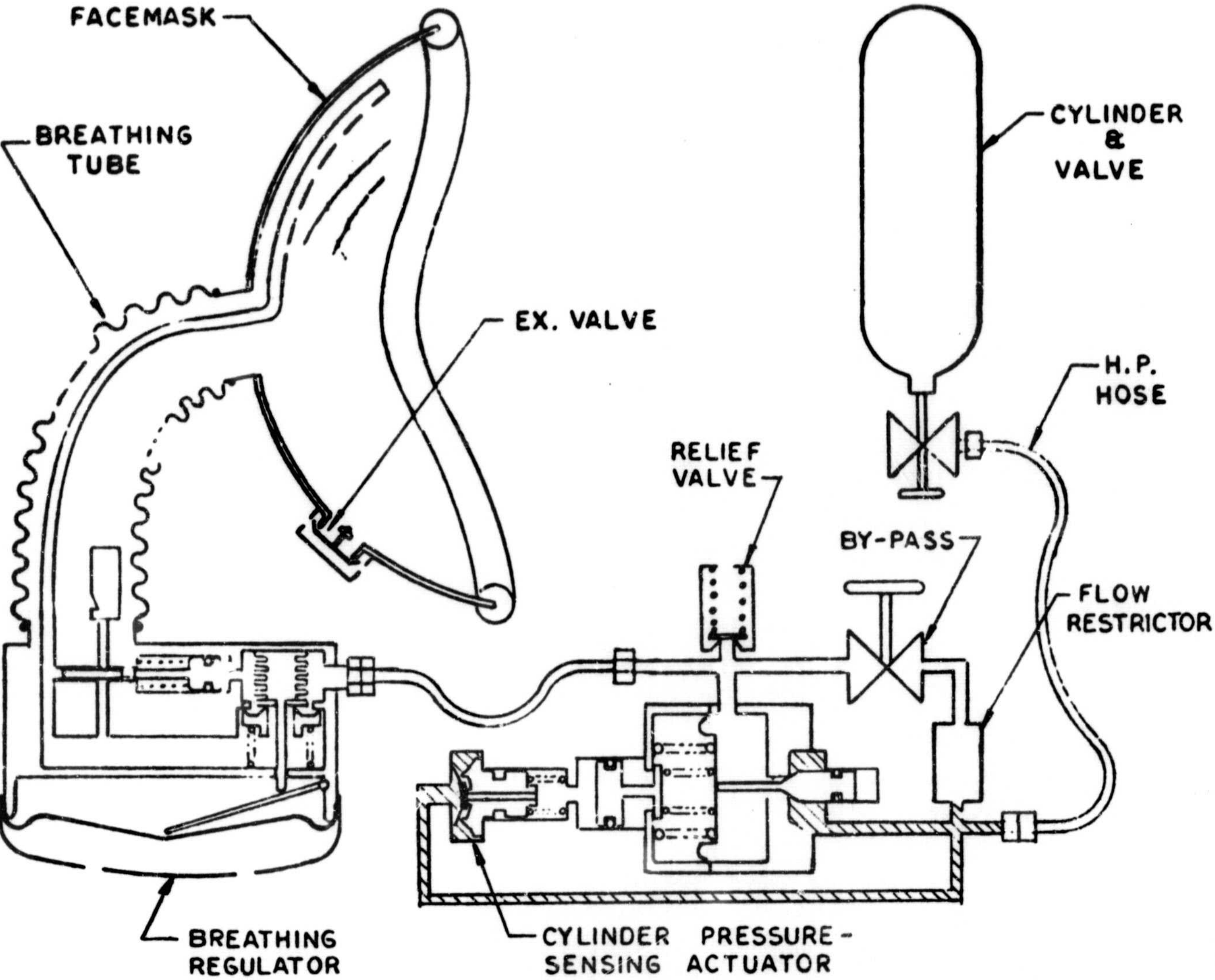
Fig. 13



SYSTEM F

System identical to that shown in Fig. 9, except that the breathing regulator is chest mounted. A low pressure breathing tube containing a discharge line to the spray bar connects the breathing regulator with the facemask. Audible low pressure warning signal is transmitted through the breathing tube.

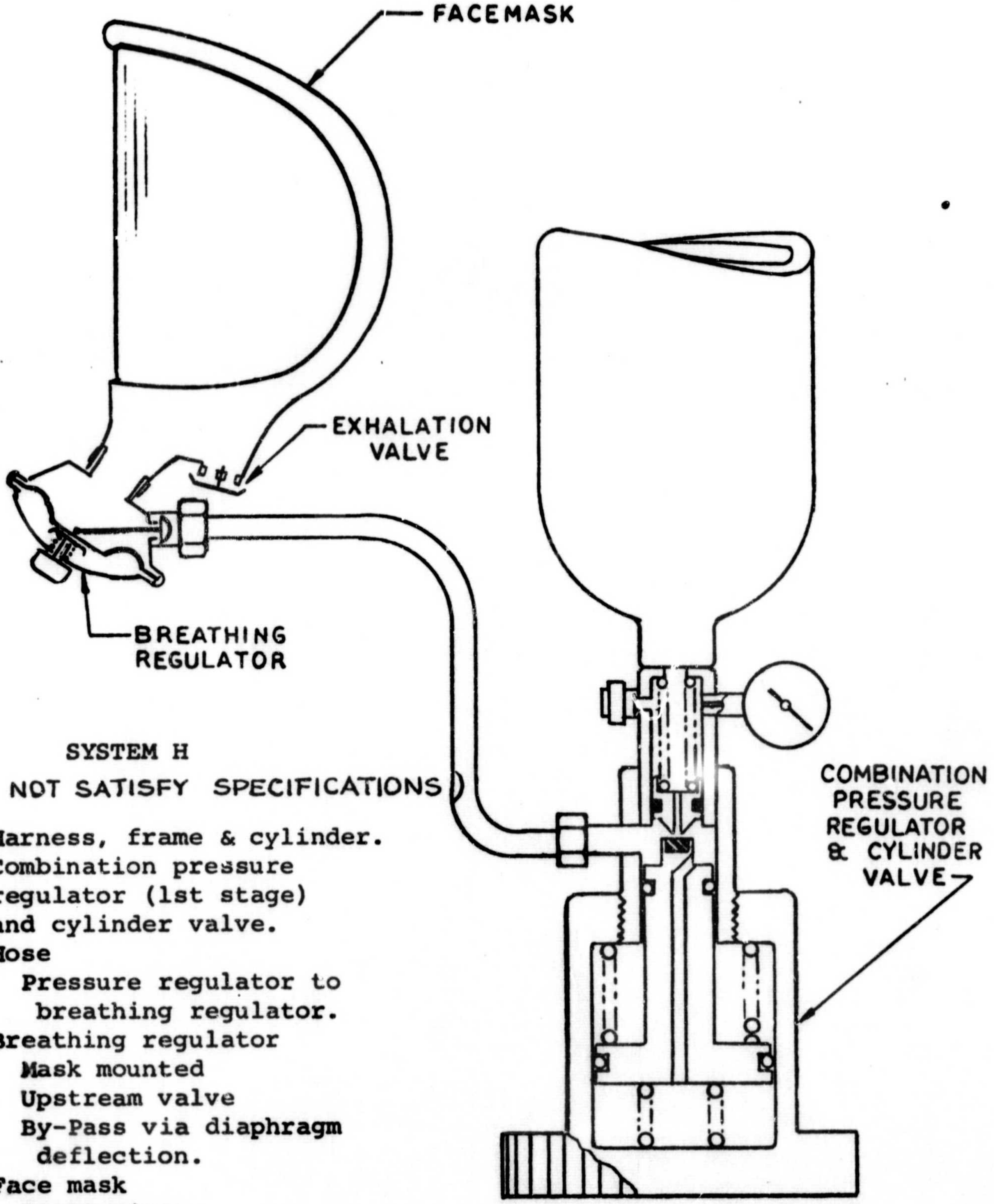
Fig. 14



SYSTEM G

System identical to that shown in Fig.10 , except that the breathing regulator is chest mounted. A low pressure breathing tube, containing a discharge line to the spray bar, connects the breathing regulator with the facemask. Audible low pressure warning signal is transmitted through the breathing tube.

Fig. 15



SYSTEM H

(DOES NOT SATISFY SPECIFICATIONS)

1. Harness, frame & cylinder.
2. Combination pressure regulator (1st stage) and cylinder valve.
3. Hose
   Pressure regulator to breathing regulator.
4. Breathing regulator
   Mask mounted
   Upstream valve
   By-Pass via diaphragm deflection.
5. Face mask
   Scottovista
   Exhalation

Fig. 16

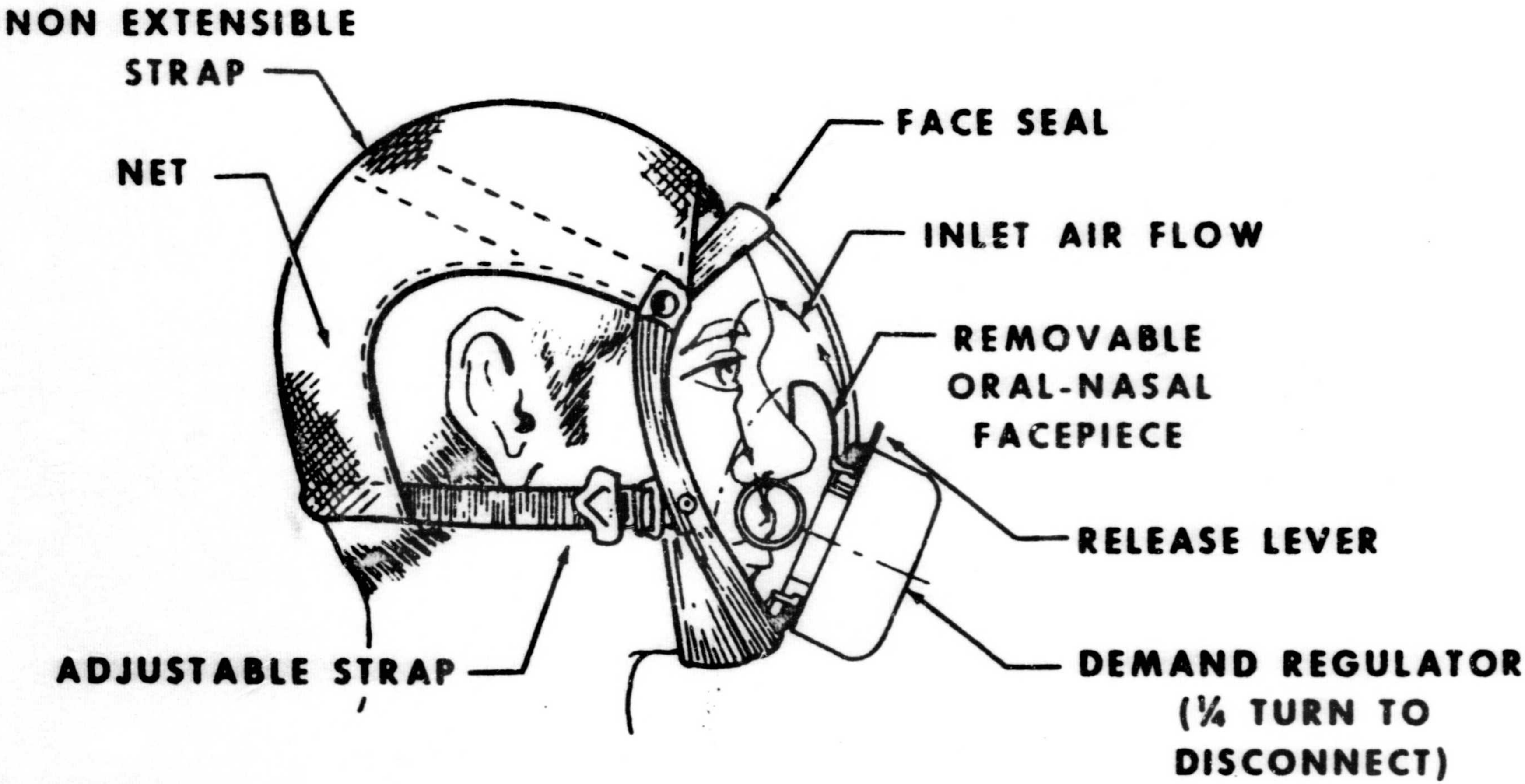
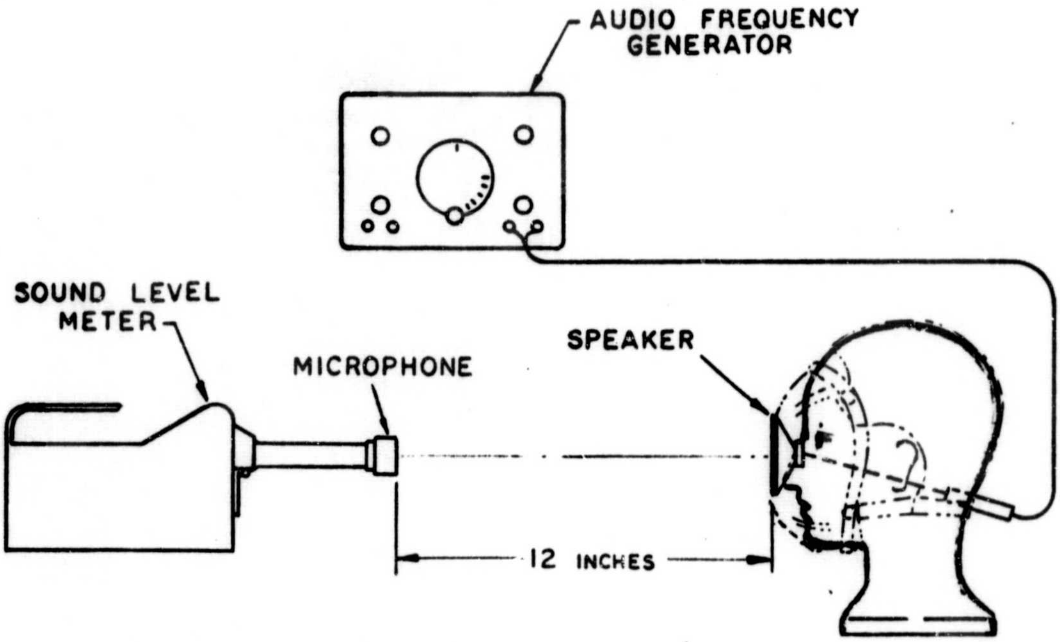

NON EXTENSIBLE
STRAP
NET
FACE SEAL
INLET AIR FLOW
REMOVABLE
ORAL-NASAL
FACEPIECE
RELEASE LEVER
ADJUSTABLE STRAP
DEMAND REGULATOR
(¼ TURN TO
DISCONNECT)

FIGURE 17

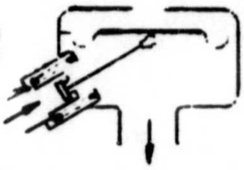
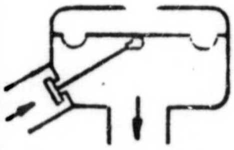
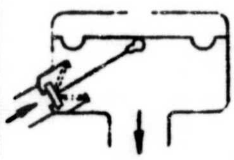
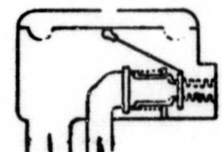
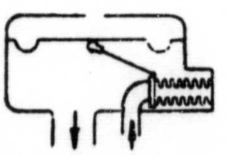
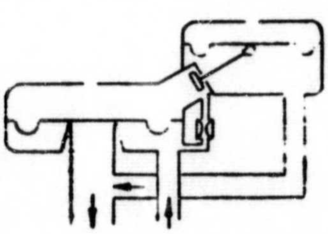
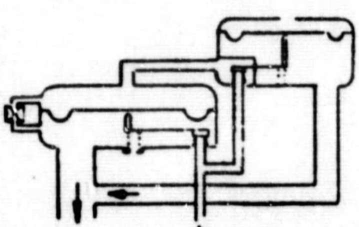


BACKGROUND 36-40 dBA

MASK	FREQUENCY			
	dBA @ 200 Hz	dBA @ 1000 Hz	dBA @ 2000 Hz	dBA @ 3000 Hz
WITHOUT MASK	72	78	86	89
MASK A - WITH SPEAKING DIAPHRAGM	55	56	64	59
MASK A - WITHOUT SPEAKING DIAPHRAGM	45	46	55	52
MASK B - NO SPEAKING DIAPHRAGM	50	48	62	51
MASK C - WITH SPEAKING DIAPHRAGM	54	64	81	67
MASK D - WITH SPEAKING DIAPHRAGM	56	61	74	72
MASK E - WITHOUT SPEAKING DIAPHRAGM	53	56	58	60
MASK E - WITH SPEAKING DIAPHRAGM	48	57	63	65
NASA MASK NO SPEAKING DIAPHRAGM	56	57	76	66

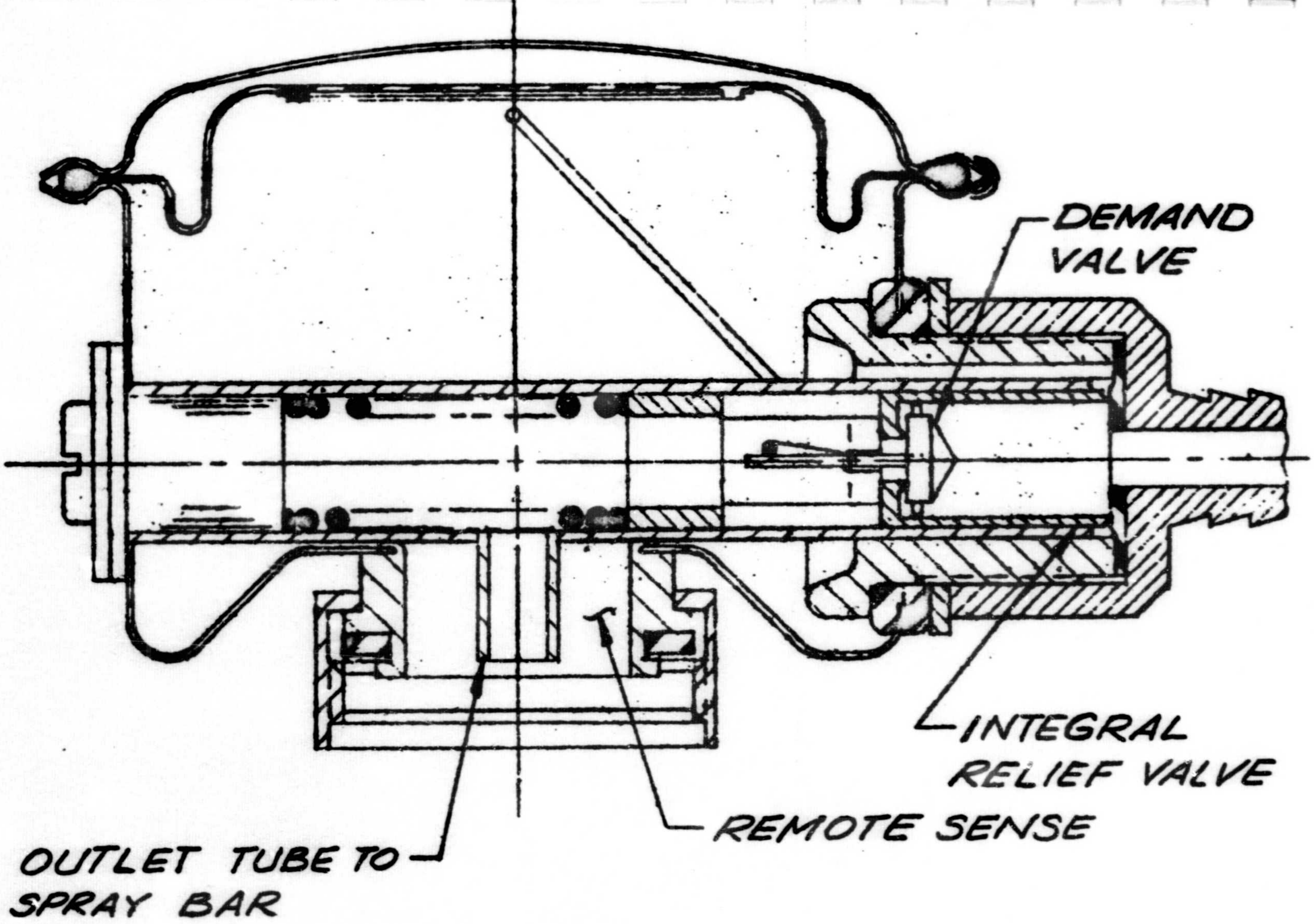
SOUND TRANSMISSION THROUGH FACEMASKS

FIG. 18

VALVE STYLE	ADVANTAGES	DISADVANTAGES
PRESSURE CLOSING (UPSTREAM) VALVE  WITH INTEGRAL RELIEF 	Minimum parts. Low cost. Simple, proven design Readily maintainable. Stable performance.	Performance limited by cracking force (valve size). Large package size. Large stroke required. Requires separate relief. Remote sensing not easily accomplished. Cracking force proportional to supply pressure.
PRESSURE OPENING (DOWNSTREAM) VALVE 	Minimum parts. Low cost. Simple, proven design Stable performance Readily maintainable. Self relieving.	Performance limited by valve size. Large package size. Large stroke required. Cracking force inversely proportional to supply pressure. High cracking pressure due to requirement to hold back maximum supply pressures.
BALANCED VALVE  WITH INTEGRAL RELIEF 	Few parts. Cracking force relatively insensitive to supply pressure. Moderate package size. Moderate stroke required. High flow capacity.	Moderate cost. Moderate complexity. Poor lock-up characteristics. Separate relief required.
PILOT VALVE PRESSURE CLOSING PILOT & MAIN VALVES 	Minimum package size. Minimum weight. Very high flow capacity. Minimum draft required. Ducted flow and remote sensing easily accomplished Cracking force insensitive to supply pressure.	Most parts. Most expensive. Most complex. Flow unstable (on-off action) Poor maintenance characteristics. Small diaphragm stroke required.
PILOT VALVE PRESSURE OPENING PILOT & MAIN VALVES 	Minimum package size. Minimum weight. Very high flow capacity. Ducted flow and remote sensing easily accomplished Minimum draft. Self relieving. Cracking force insensitive to supply pressure.	Most parts. Most expensive. Most complex. Flow unstable (on-off action). Poor maintenance characteristics. Small diaphragm stroke

DEMAND REGULATOR DESIGN CONCEPTS

FIGURE 19



SECTIONAL VIEW OF
DEMAND REGULATOR WITH
INTEGRAL RELIEF
Fig. 20

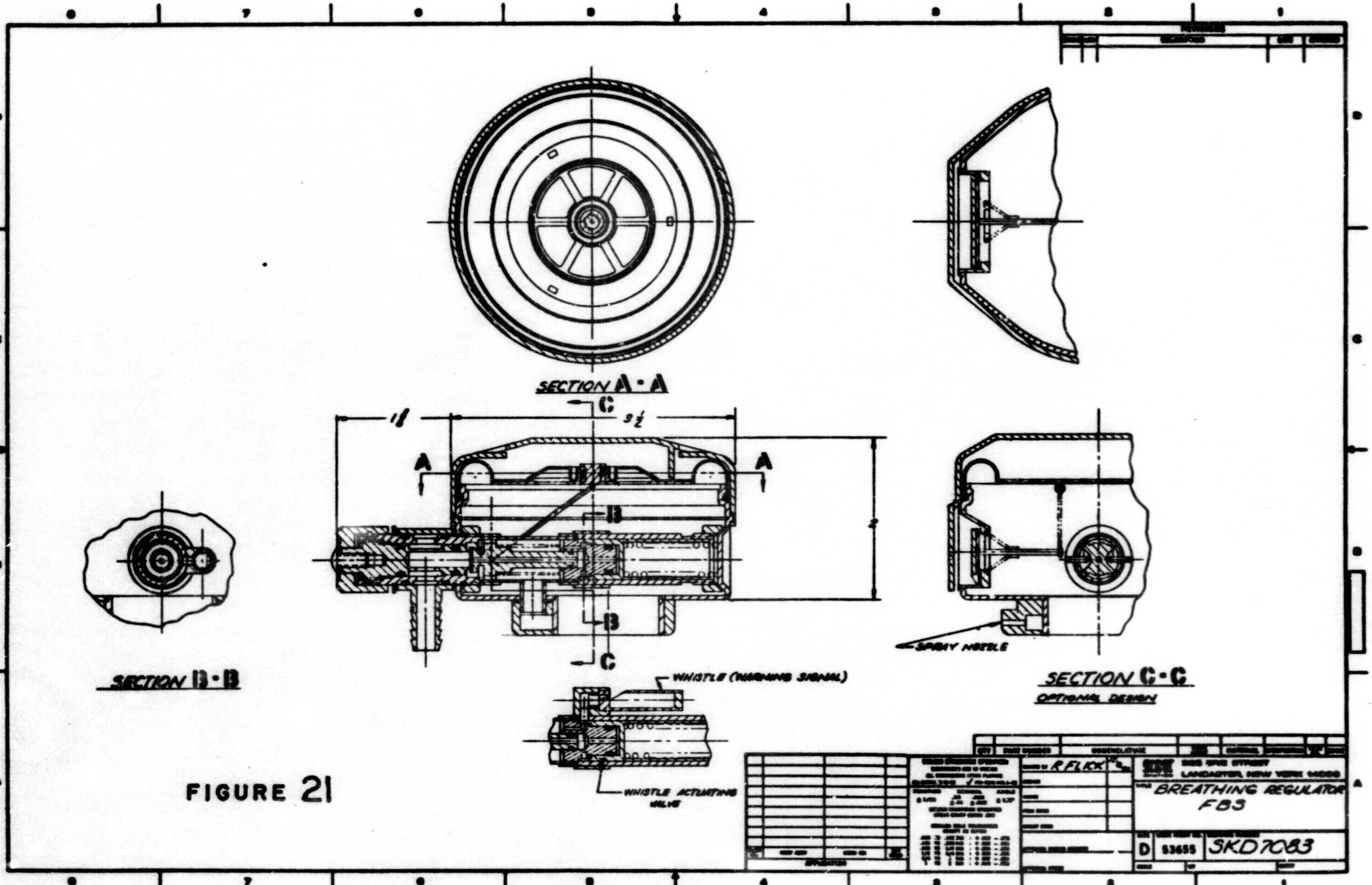

SECTION A-A
SECTION B-B
SECTION C-C
OPTIONAL DESIGN
SPRAY NOZZLE
WHISTLE (WARNING SIGNAL)
WHISTLE ACTUATING VALVE
R FLICK
BREATHING REGULATOR
FBS
53655
SKD7083
LANCASTER, NEW YORK

FIGURE 21

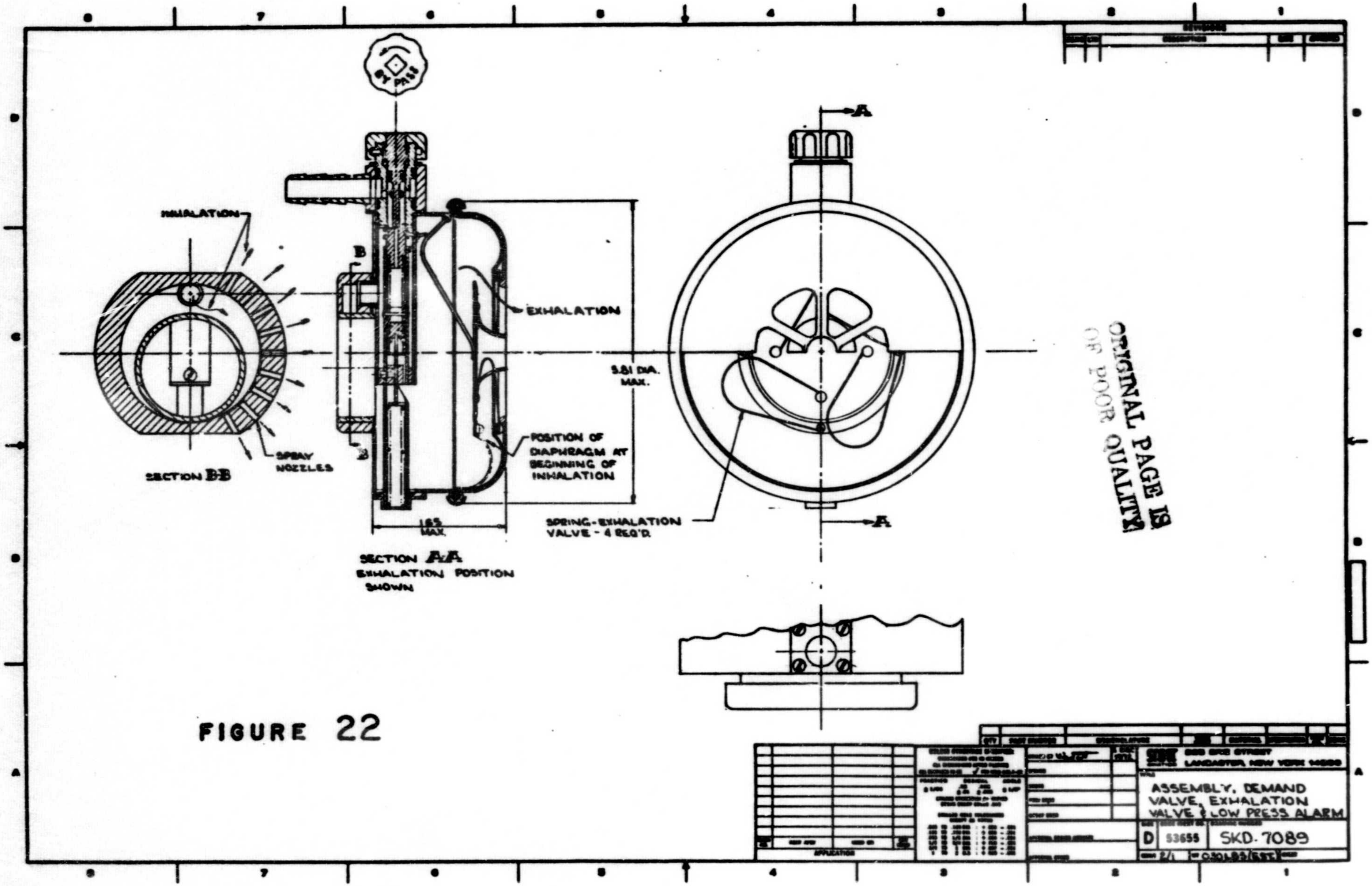

BY PASS
INHALATION
B
EXHALATION
5.81 DIA. MAX.
POSITION OF DIAPHRAGM AT BEGINNING OF INHALATION
SPRAY NOZZLES
SECTION B-B
1.65 MAX.
SPRING-EXHALATION VALVE - 4 REQ'D.
SECTION A-A
EXHALATION POSITION SHOWN
A
ORIGINAL PAGE IS OF POOR QUALITY
LANCASTER, NEW YORK 14086
ASSEMBLY, DEMAND VALVE, EXHALATION VALVE & LOW PRESS ALARM
D
53655
SKD-7089
APPLICATION

FIGURE 22

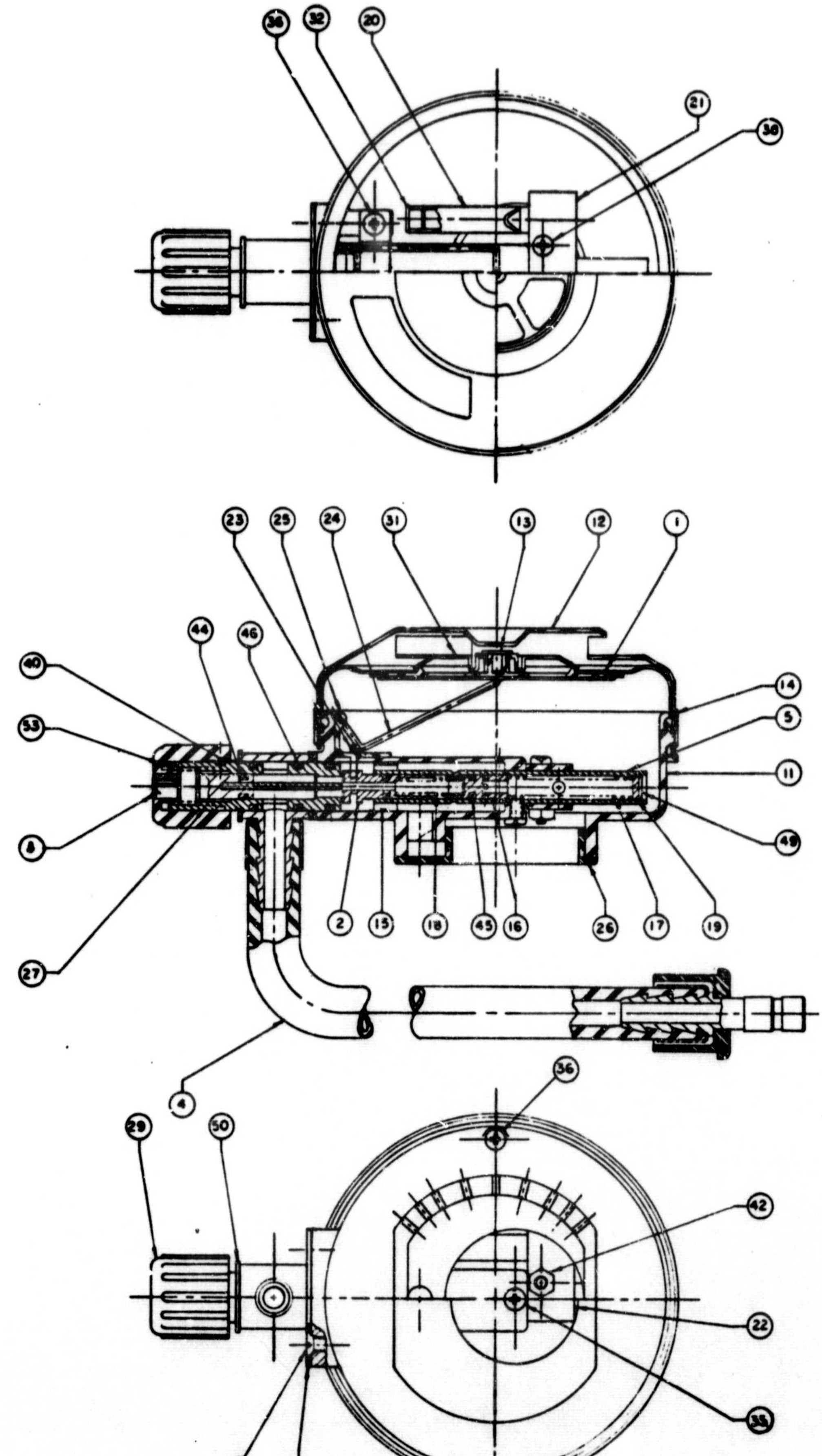
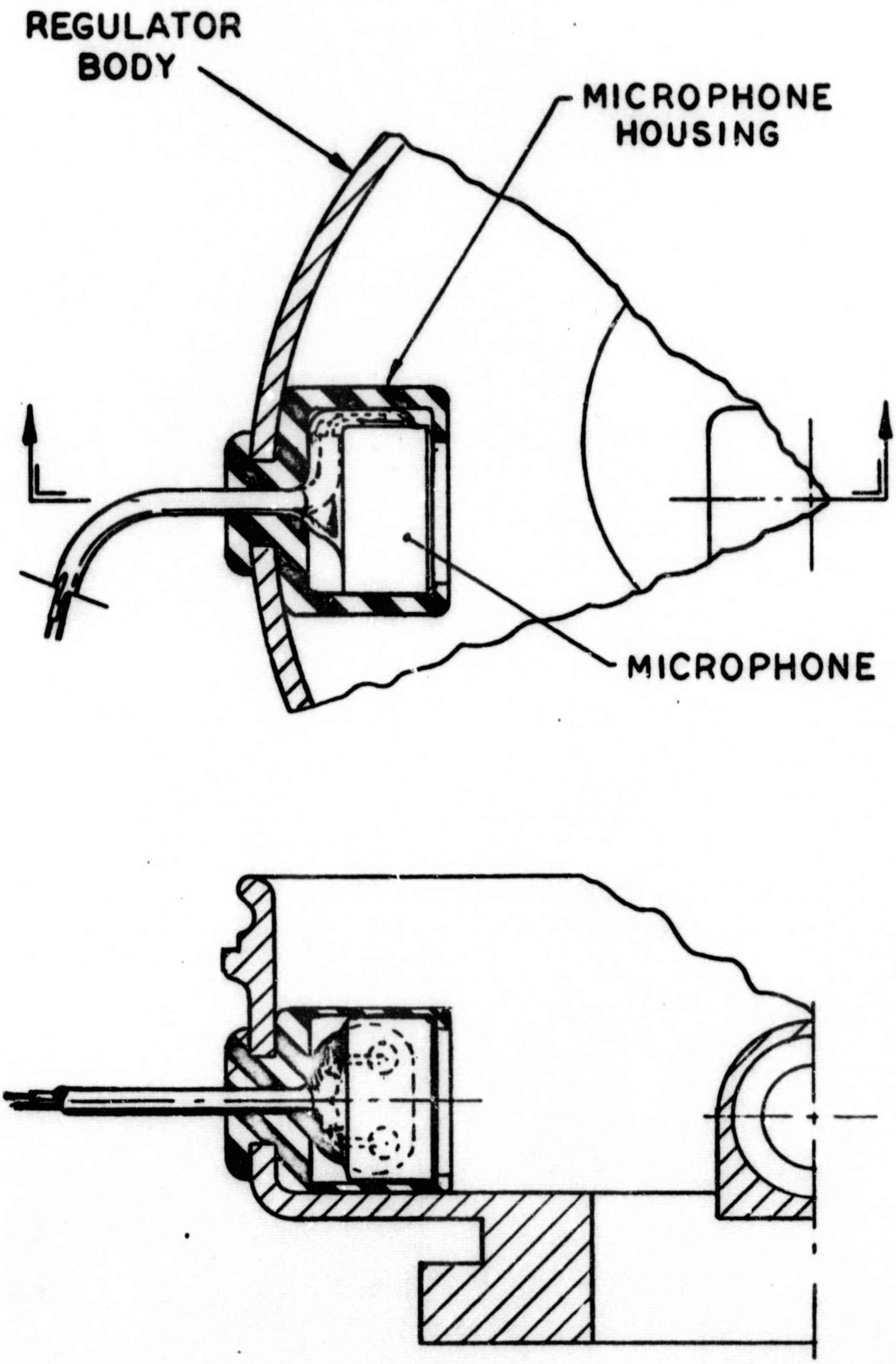
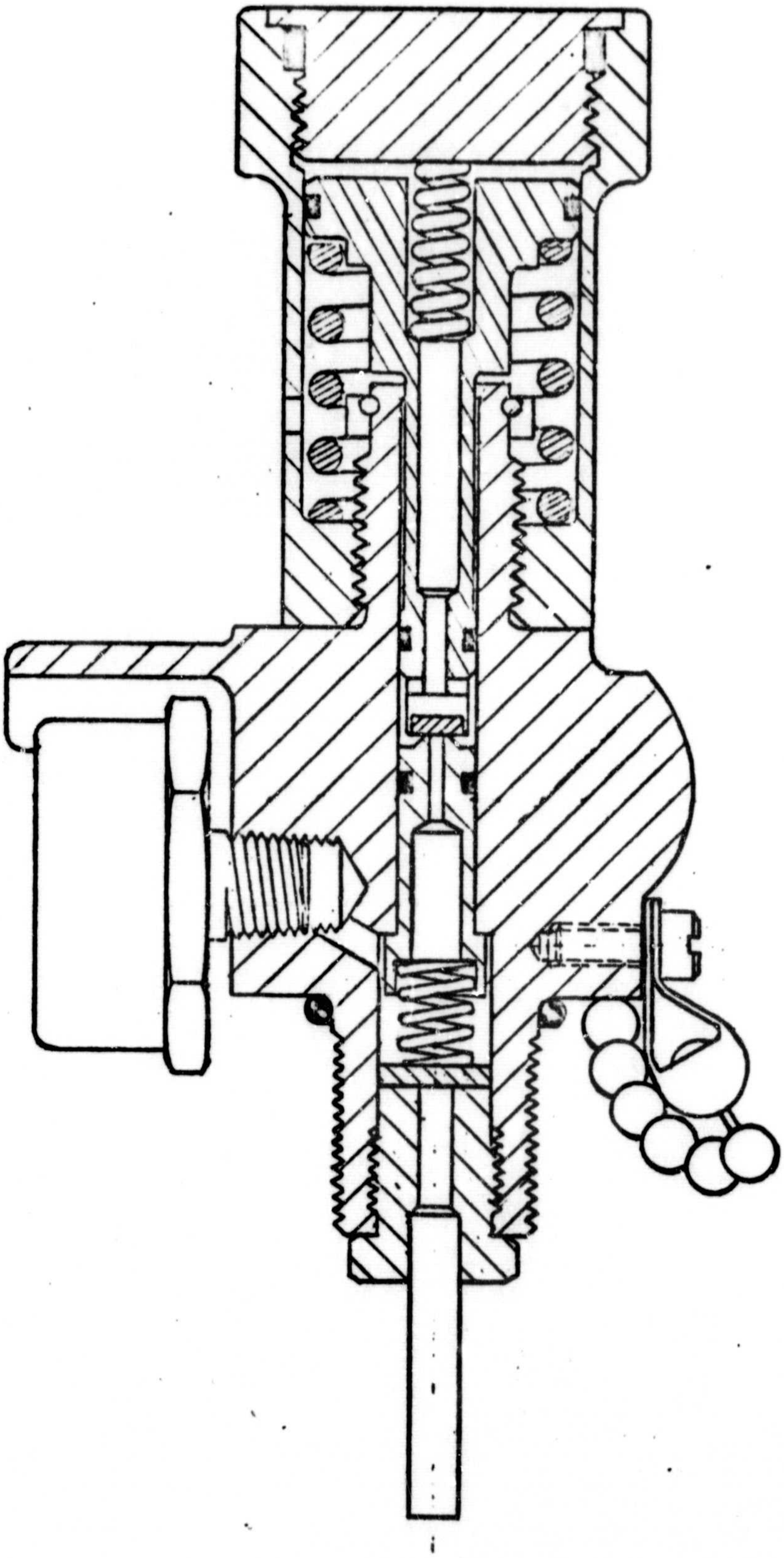

36
32
20
21
38
23
25
24
31
13
12
1
44
46
40
53
14
5
11
8
49
2
15
18
45
16
26
17
19
27
4
36
29
50
42
22
35
37
30

FIGURE 23



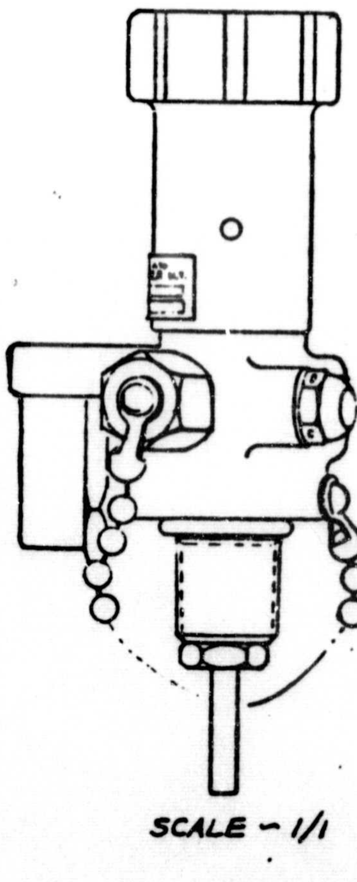
MICROPHONE INSTALLATION

FIGURE 24



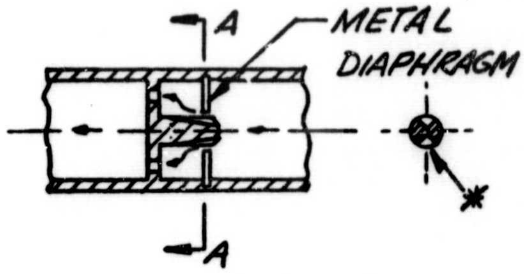
COMBINATION
CYLINDER VALVE AND REGULATOR

Fig. 25

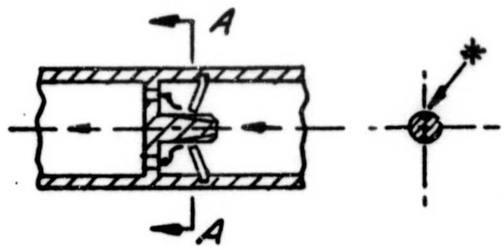


SCALE – 1/1

METALLIC FLOW CONTROLLER



LOW ΔP

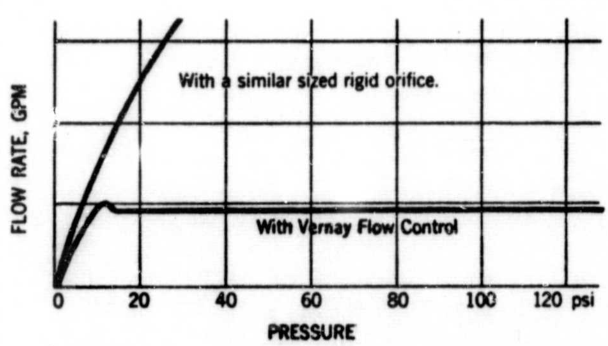


HIGH ΔP

* V GROOVES PROFILED TO APPROACH CONSTANT GAS FLOW AT VARIABLE ΔP

RUBBER FLOW CONTROLS

TYPICAL INSTALLATIONS



VERNAY LABORATORIES, INC.

Maintains consistent volume output with varying inlet pressures. No moving parts. Control flow ranges of .03 to 30 gallons per minute (0.1 to 114 liters/minute). Temperature range of −65° to 500°F (−50° to 260°C). Reproducible flow in low and high pressure ranges.

ADVANTAGES: Can be compounded for specific fluid systems employing water, gas, oils and fuels. Quiet operation. Once installed, requires no adjustment or servicing.

APPLICATIONS: Inexpensive controls for time fill devices, automatic washing machines and dishwashers, vending machines, showers, faucets and plumbing valves, drinking fountains, gas valves, automotive transmission controls, automatic ice cubers, water-cooled equipment, water softeners, fuel systems, automotive cooling systems, machine tools, etc.

FLOW FUSES

FIGURE 26

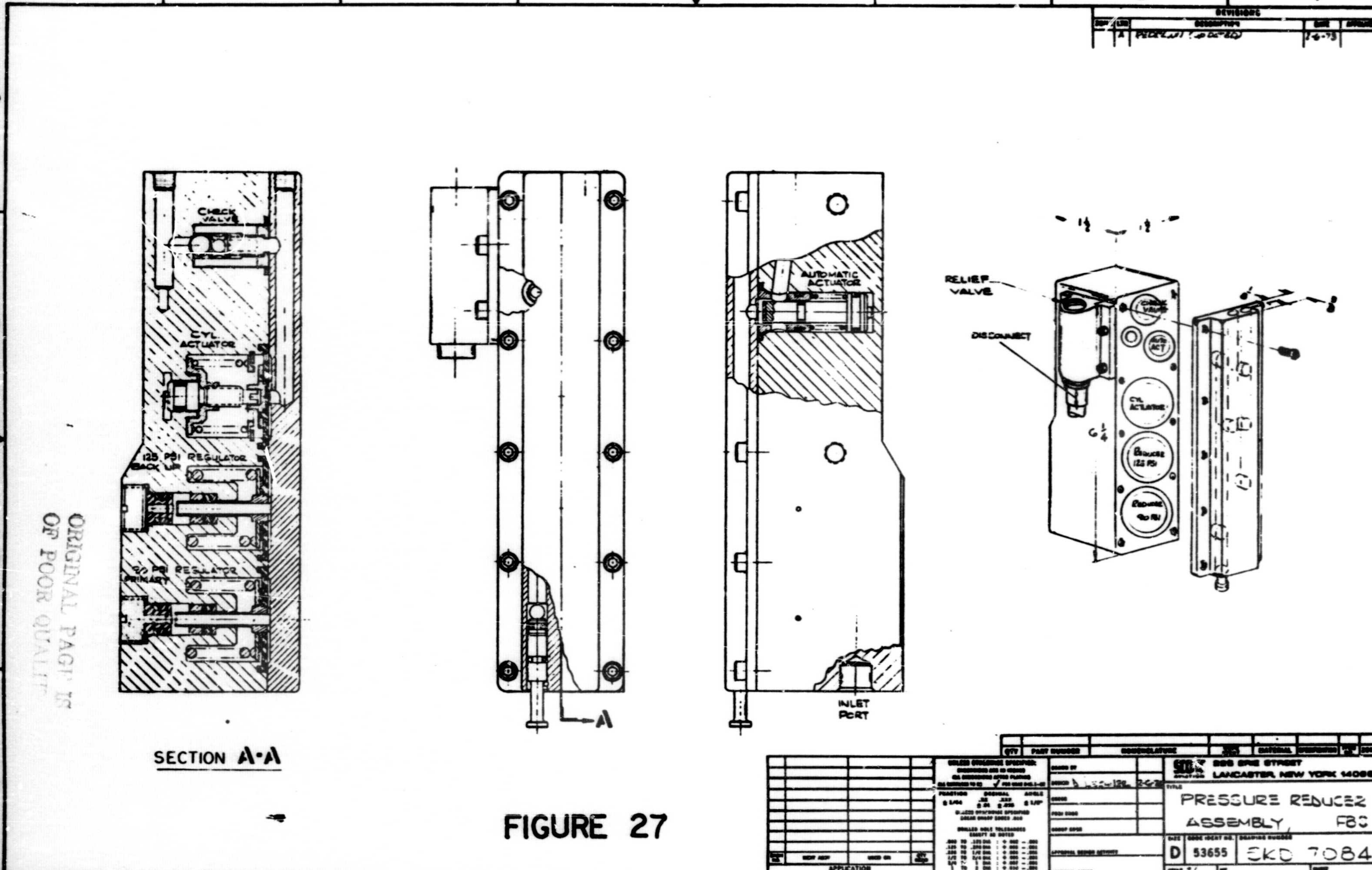
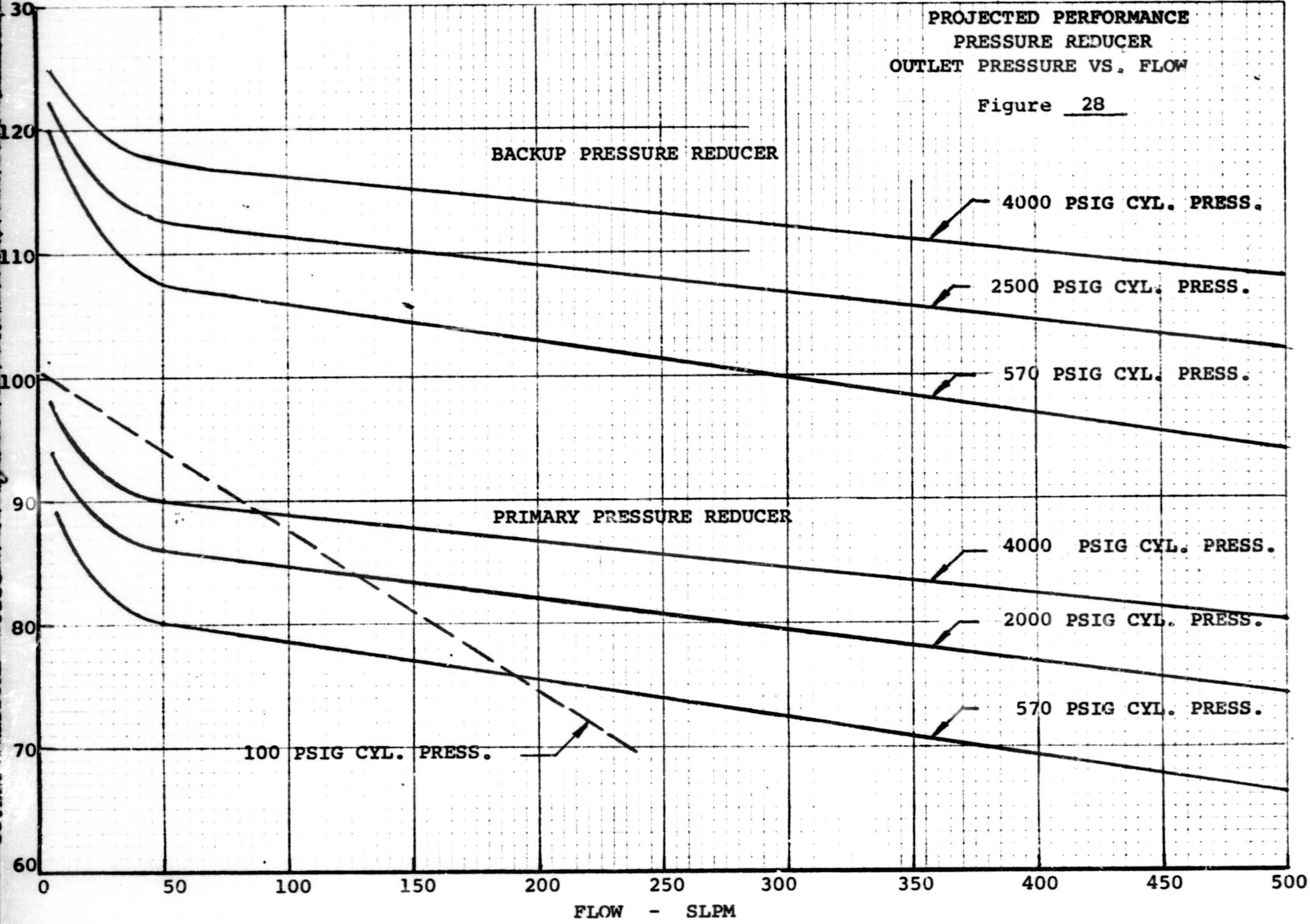
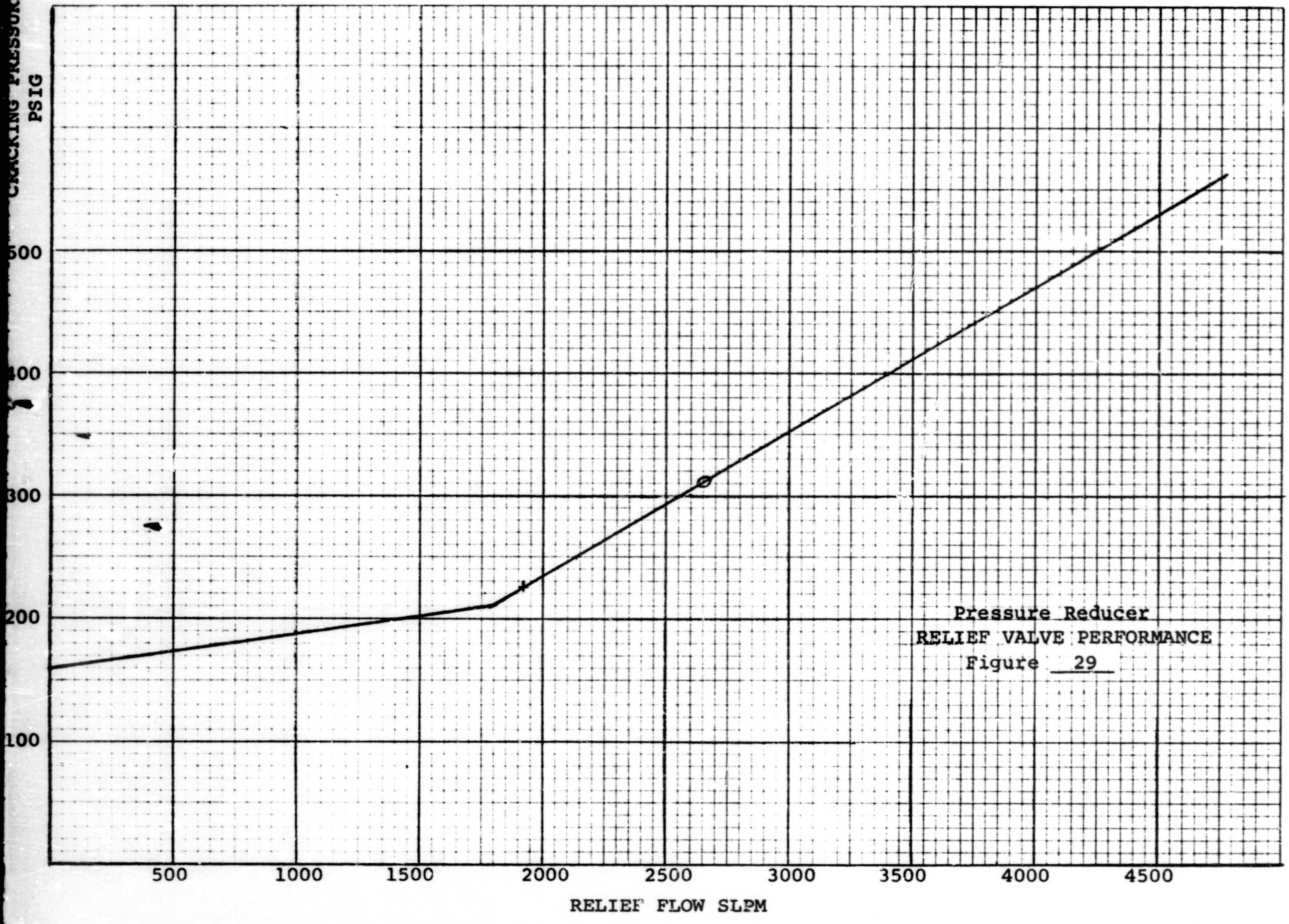
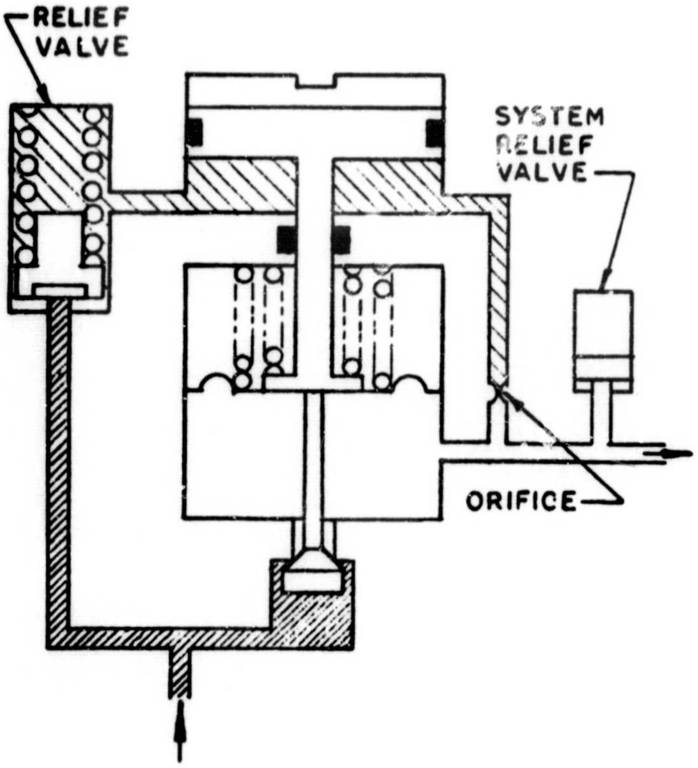

CHECK VALVE
CYL ACTUATOR
125 PSI REGULATOR BACK UP
90 PSI REGULATOR PRIMARY
SECTION A-A
A
AUTOMATIC ACTUATOR
INLET PORT
RELIEF VALVE
DISCONNECT
CHECK VALVE
AUTO ACT
CYL ACTUATOR
REDUCER 125 PSI
REDUCER 90 PSI
6 1/4
REVISIONS
LANCASTER, NEW YORK 14086
PRESSURE REDUCER ASSEMBLY, FBC
D
53655
EKD 7084
APPLICATION

FIGURE 27


PROJECTED PERFORMANCE
PRESSURE REDUCER
OUTLET PRESSURE VS. FLOW
Figure 28
BACKUP PRESSURE REDUCER
4000 PSIG CYL. PRESS.
2500 PSIG CYL. PRESS.
570 PSIG CYL. PRESS.
PRIMARY PRESSURE REDUCER
4000 PSIG CYL. PRESS.
2000 PSIG CYL. PRESS.
570 PSIG CYL. PRESS.
100 PSIG CYL. PRESS.
130
120
110
100
90
80
70
60
0
50
100
150
200
250
300
350
400
450
500
FLOW - SLPM



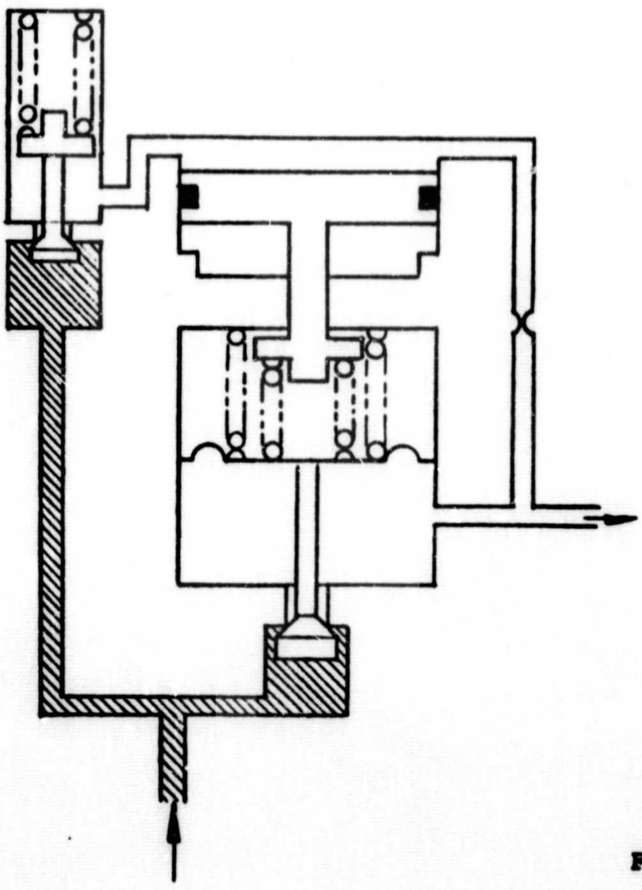
Pressure Reducer
RELIEF VALVE PERFORMANCE
Figure 29



Flow past relief valve & back **pressure** caused by orifice **moves** piston to compress inner **spring**. A continuous bleed is **dumped** downstream, consumed or **vented** by system relief valve. **As** cylinder pressure drops to **850 psi**, relief valve closes, **orifice** vents all back pressure. **Spring** extends to increase load **on** diaphragm thereby raising **regulated** pressure.

Continuous bleed from high cylinder pressure down to 850 psi.

No bleed from 850 psi on down.



High pressure closes poppet **thereby** allowing no flow to **area** above piston. Inner **spring** is not compressed. **Regulated** outlet pressure **remains** constant. As cylinder **pressure** decreases to 850 psi, **poppet** valve opens allowing **inflow**. Flow is restricted **by** orifice. Back pressure **moves** piston to compress **spring** to increase load on **diaphragm** thereby raising **regulated** pressure.

No bleed from high cylinder pressure to 850 psi.

Continuous bleed from 850 psi on down.

Fig. 30

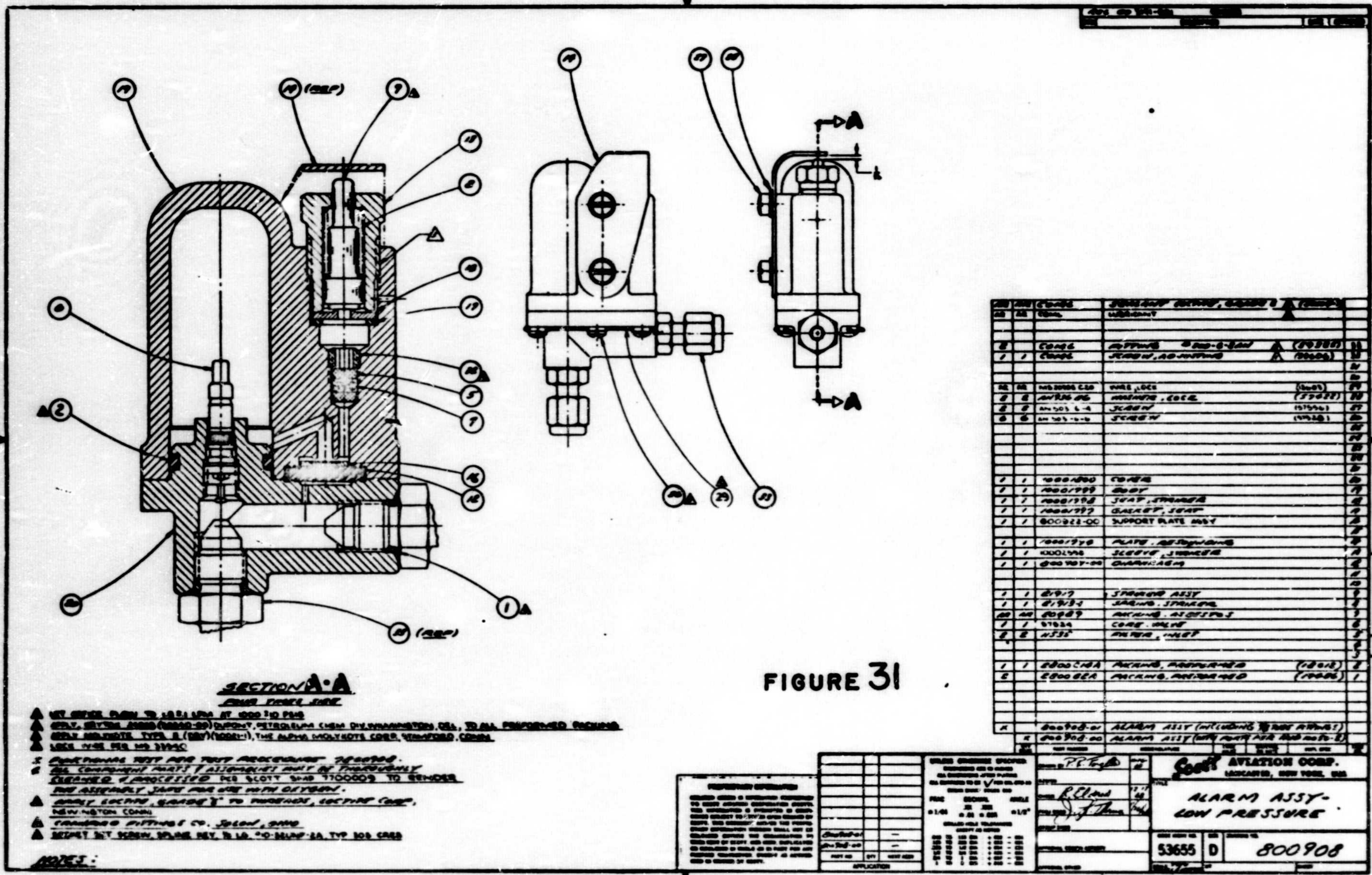


FIGURE 31

ORIGINAL PAGE IS
OF POOR QUALITY

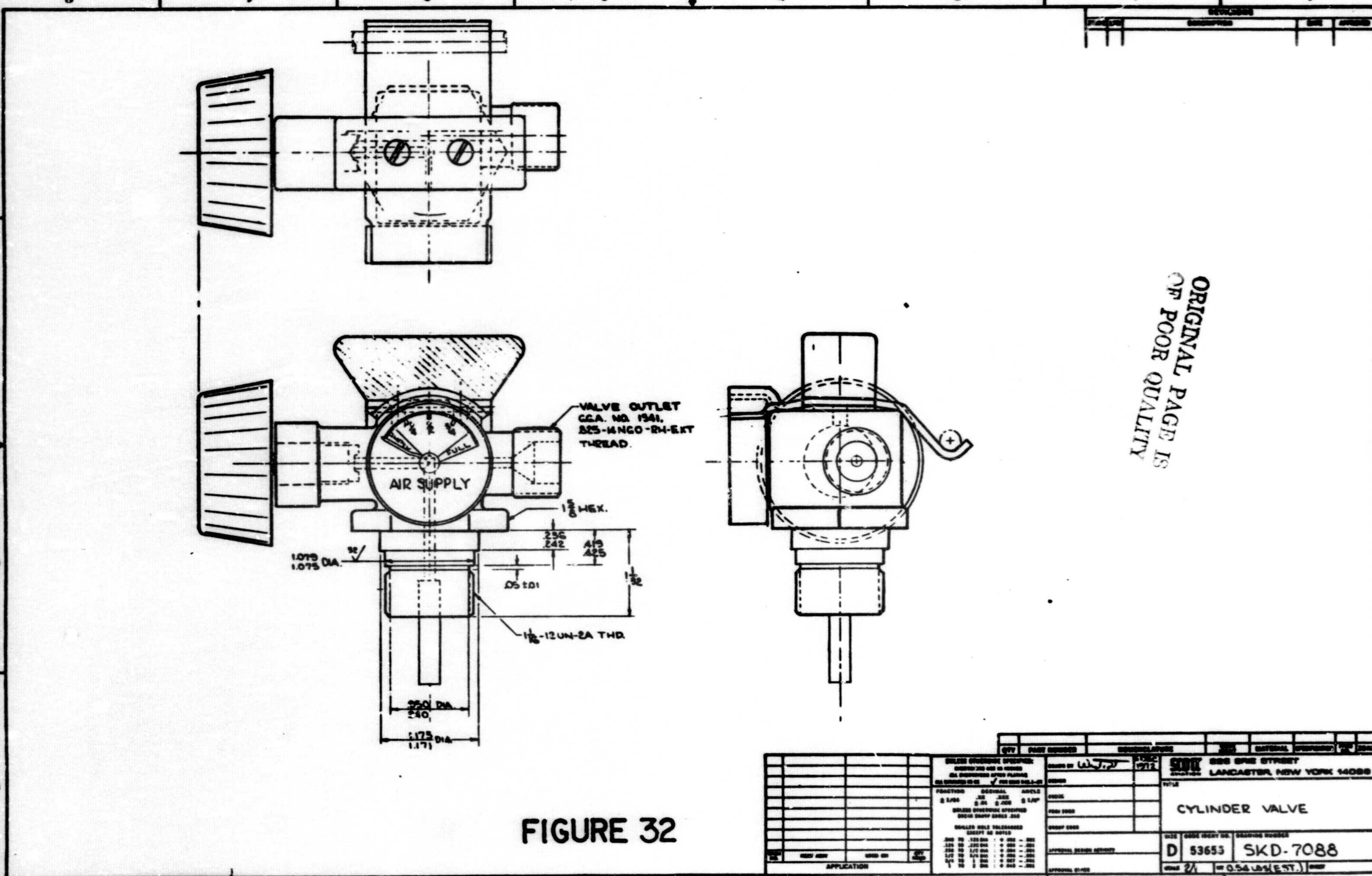

AIR SUPPLY
FULL
VALVE OUTLET
CGA. NO. 1341,
.825-14NGO-RH-EXT
THREAD.
$1\frac{5}{8}$ HEX.
.256
.242
.419
.425
$1\frac{1}{32}$
.05±.01
1.079
1.075 DIA.
32
$1\frac{1}{16}$-12UN-2A THD.
.250 DIA.
.240
1.173 DIA.
1.171
ORIGINAL PAGE IS
OF POOR QUALITY
APPLICATION
CYLINDER VALVE
D
53653
SKD-7088
2/1
0.54 LBS(EST.)
LANCASTER, NEW YORK 14086

FIGURE 32

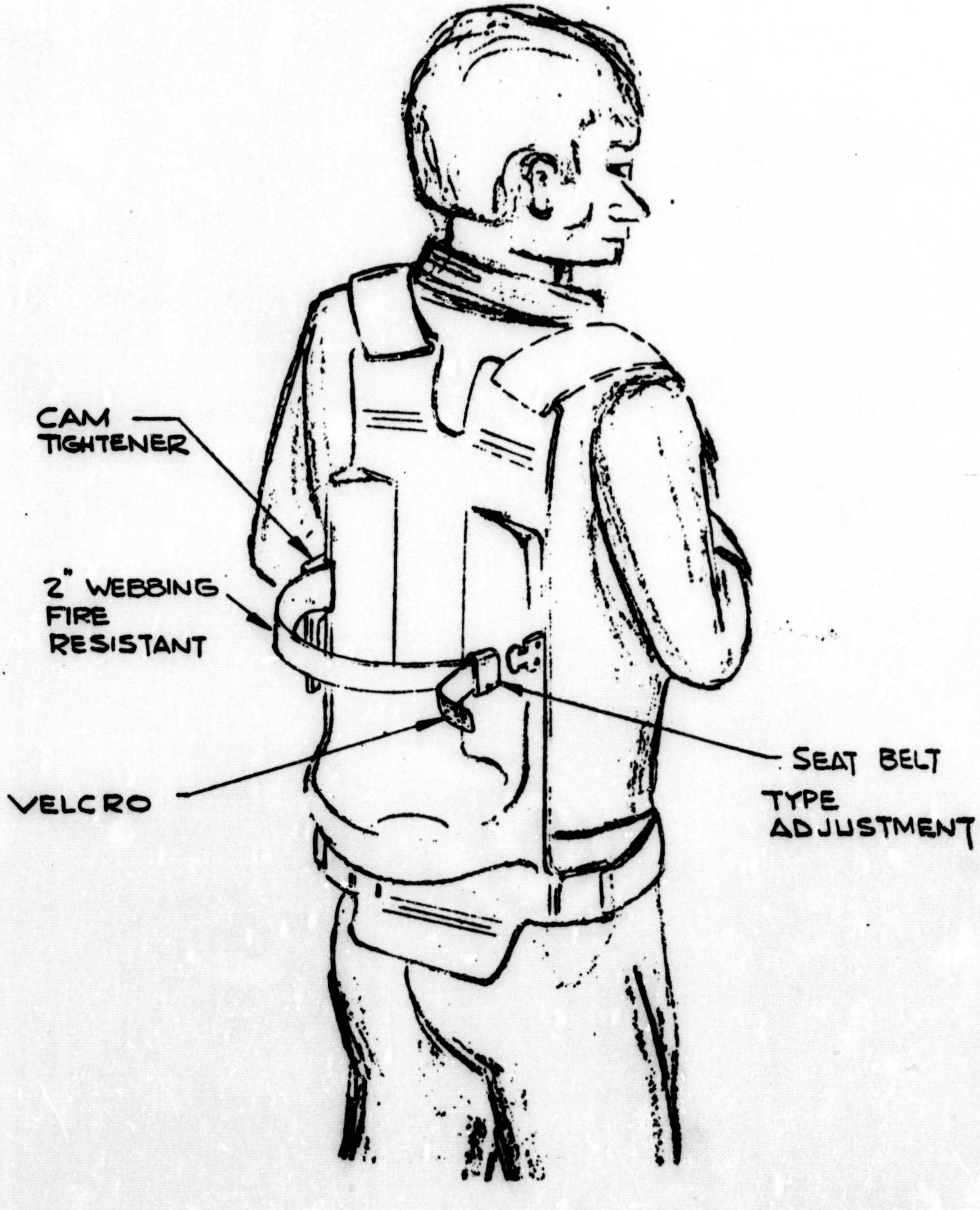


Fig. 33
MOLDED BACK-PAK

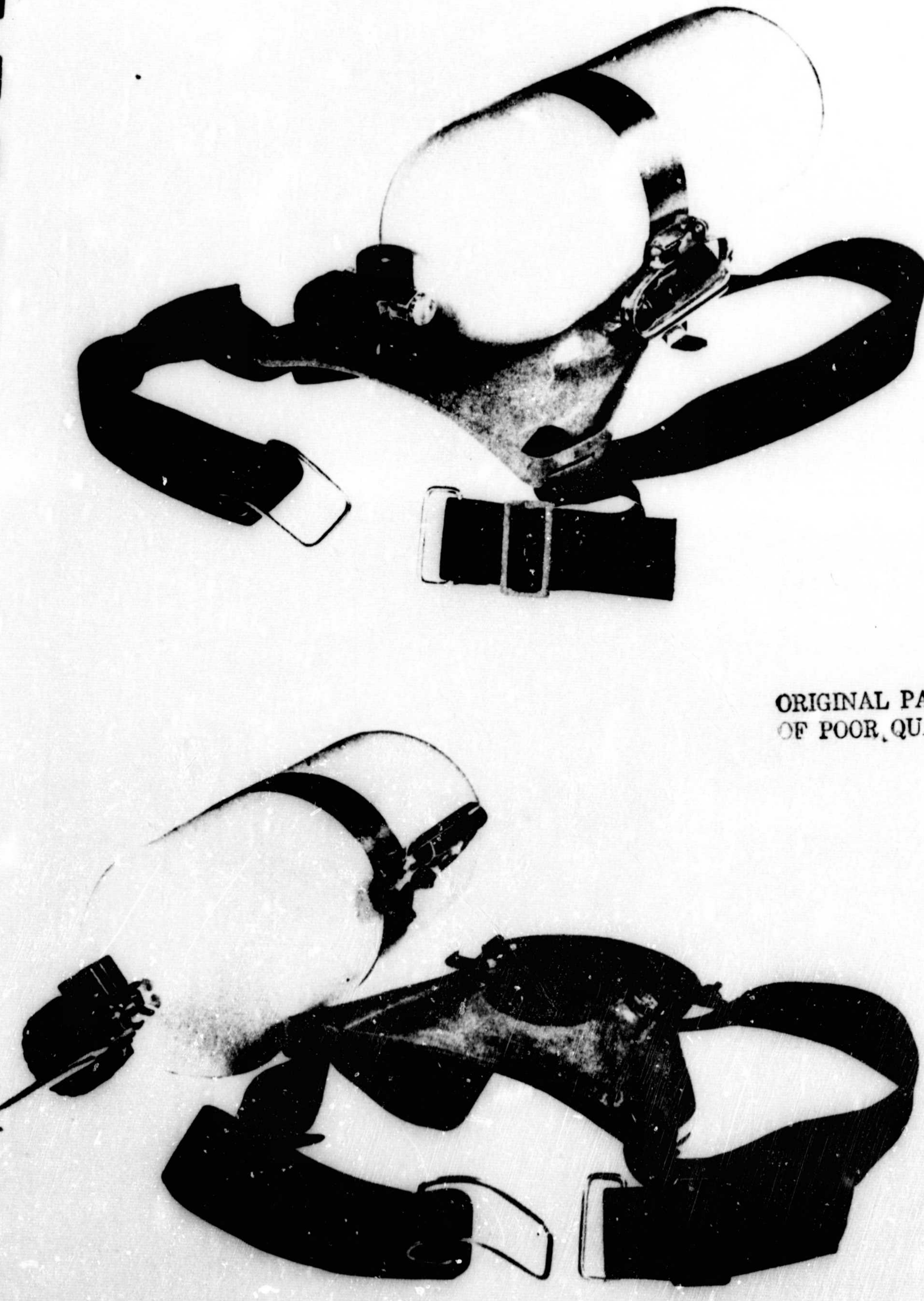
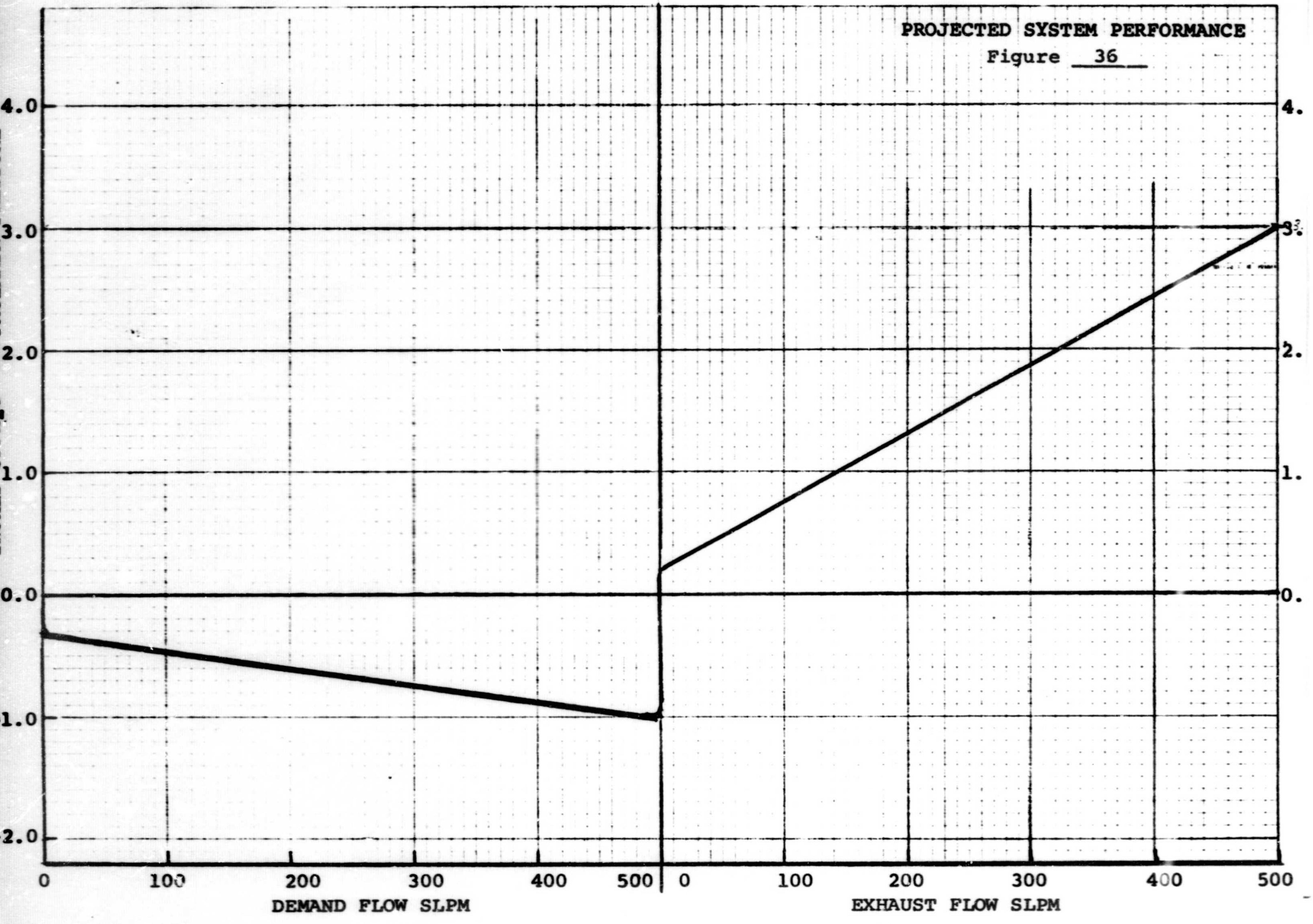


FIGURE 34
SCUBA-TYPE BACK-PAK

CYLINDER CLAMP DESIGN CONCEPTS

Description	Advantages	Disadvantages
Aluminum band with two position adjustment and a spring-type toggle clamp.	Not affected by heat. Controlled dimensions difficult to overload with clamp. Spring allows for cylinder diameter tolerances. Easy to operate with gloved hands.	Lacks infinite adjustment. Somewhat heavy.
Elastic band pulled over the cylinder and hooked to frame.	Light weight. Simplest. Infinite adjustment is possible.	Affected by heat. Difficult to operate with gloved hands.
Linked chain type belt with toggle clamp.	Infinite adjustment. Not affected by heat. Easy to operate with gloved hands.	Somewhat heavy. Thickness of band may result in snagging. Excess material of belt may become tangled. Overload of mechanism with toggle is possible.
Non-metallic web band with web adjuster and toggle clamp.	Infinite adjustment. Easy to operate with gloved hands.	Affected by heat (even though materials may be fire-resistant). Overload of mechanism with toggle is possible.
Separate adjustable band permanently connected to cylinder with mounting lugs on the band to connect with a toggle latch on the frame.	Infinite adjustment. X-tra protection for cylinder. Not affected by heat.	Each cylinder needs band. Band position on cylinder critical to mounting on frame.


PROJECTED SYSTEM PERFORMANCE
Figure 36
4.0
3.0
2.0
1.0
0.0
1.0
2.0
4.
3.
2.
1.
0.
0
100
200
300
400
500
DEMAND FLOW SLPM
EXHAUST FLOW SLPM

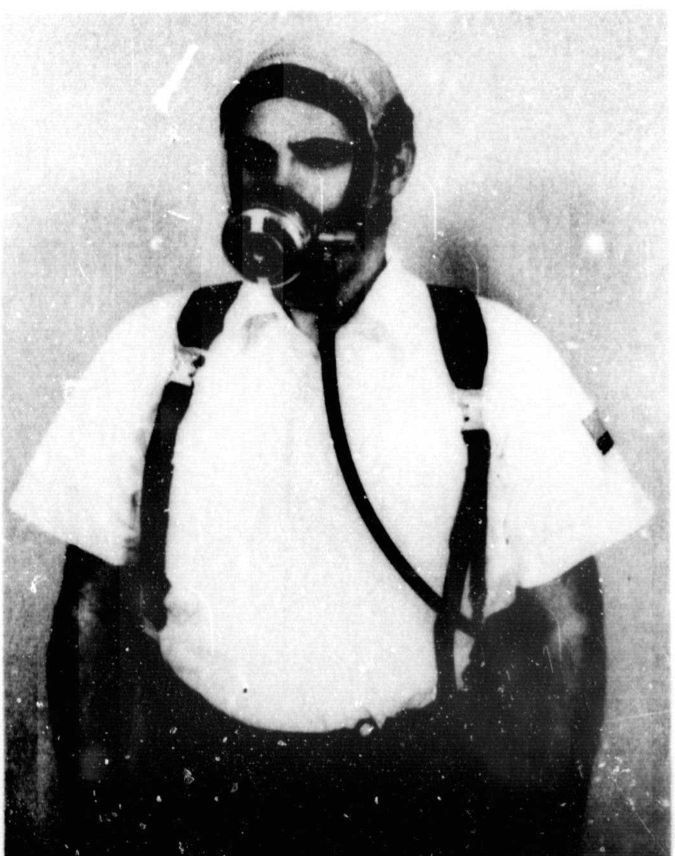


FIGURE 37

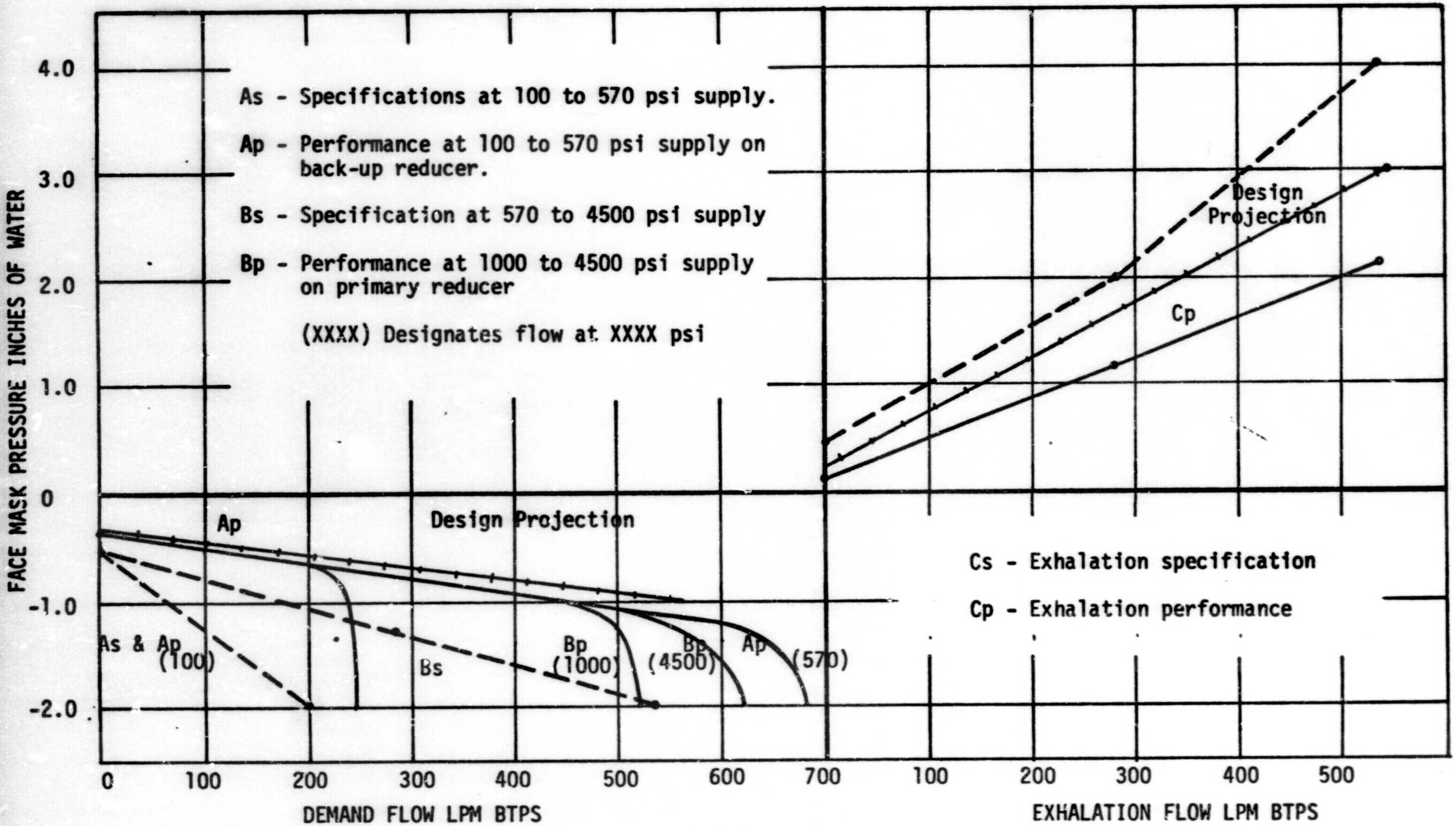


FIGURE 38

ORIGINAL SYSTEM PERFORMANCE (DEVELOPMENTAL MODELS)

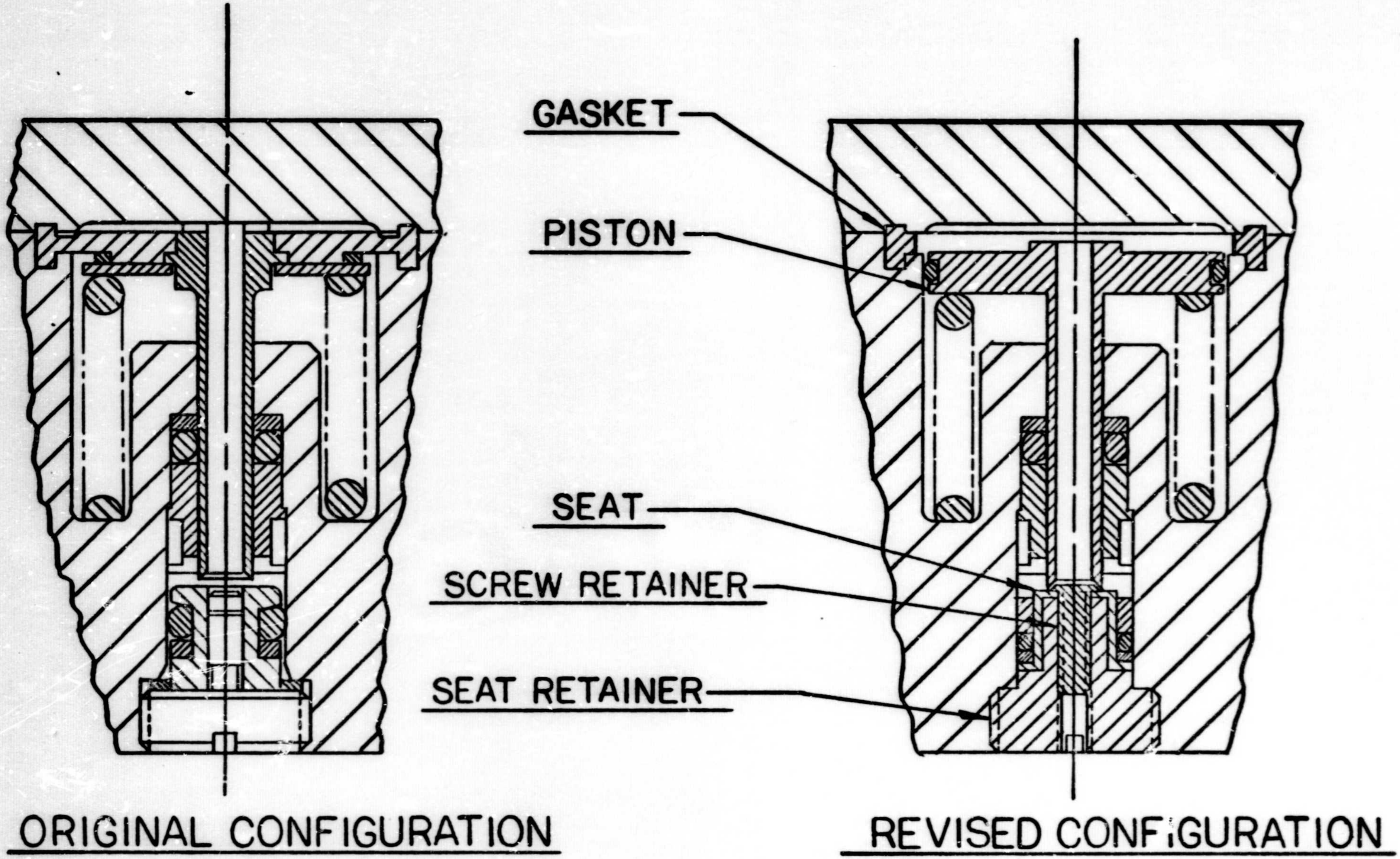


FIGURE 39

COMPARATIVE VIEW OF PRESSURE REDUCING VALVES

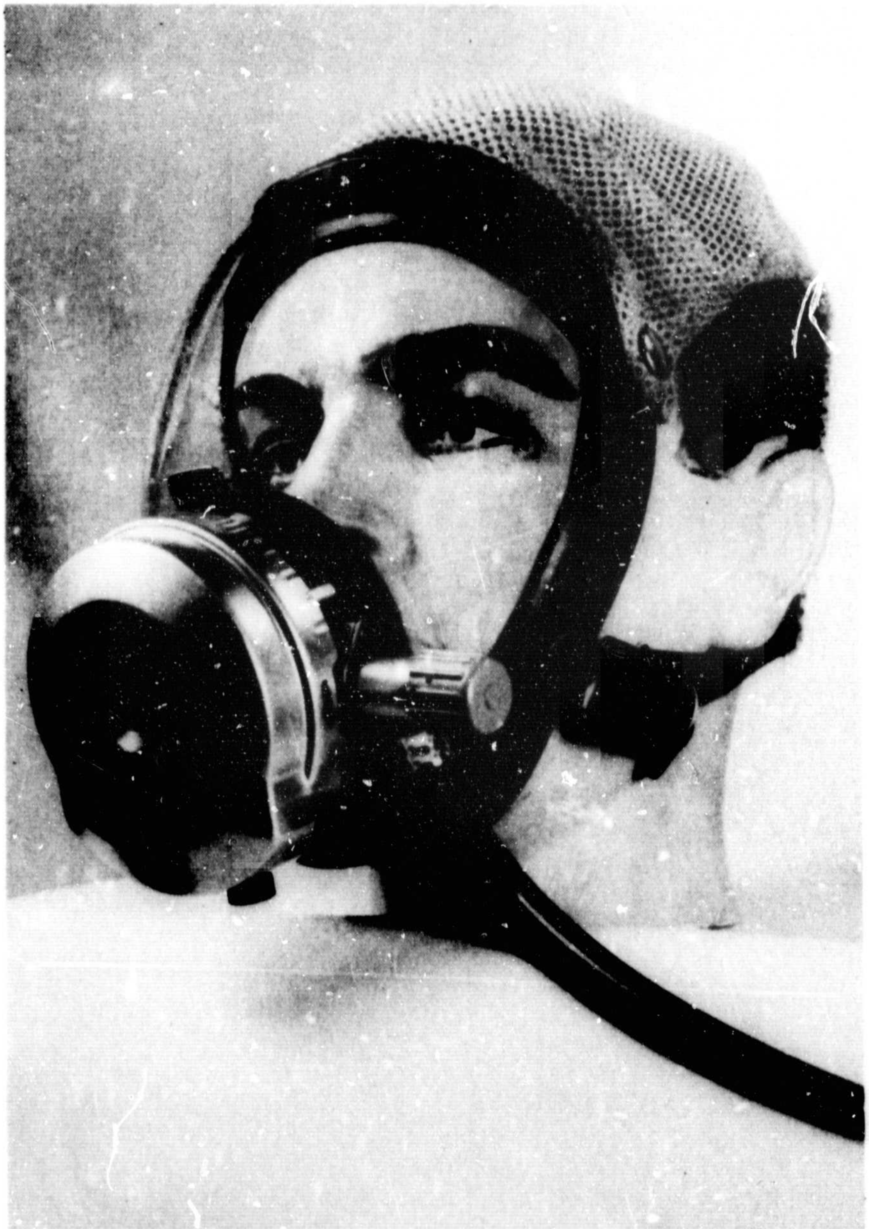
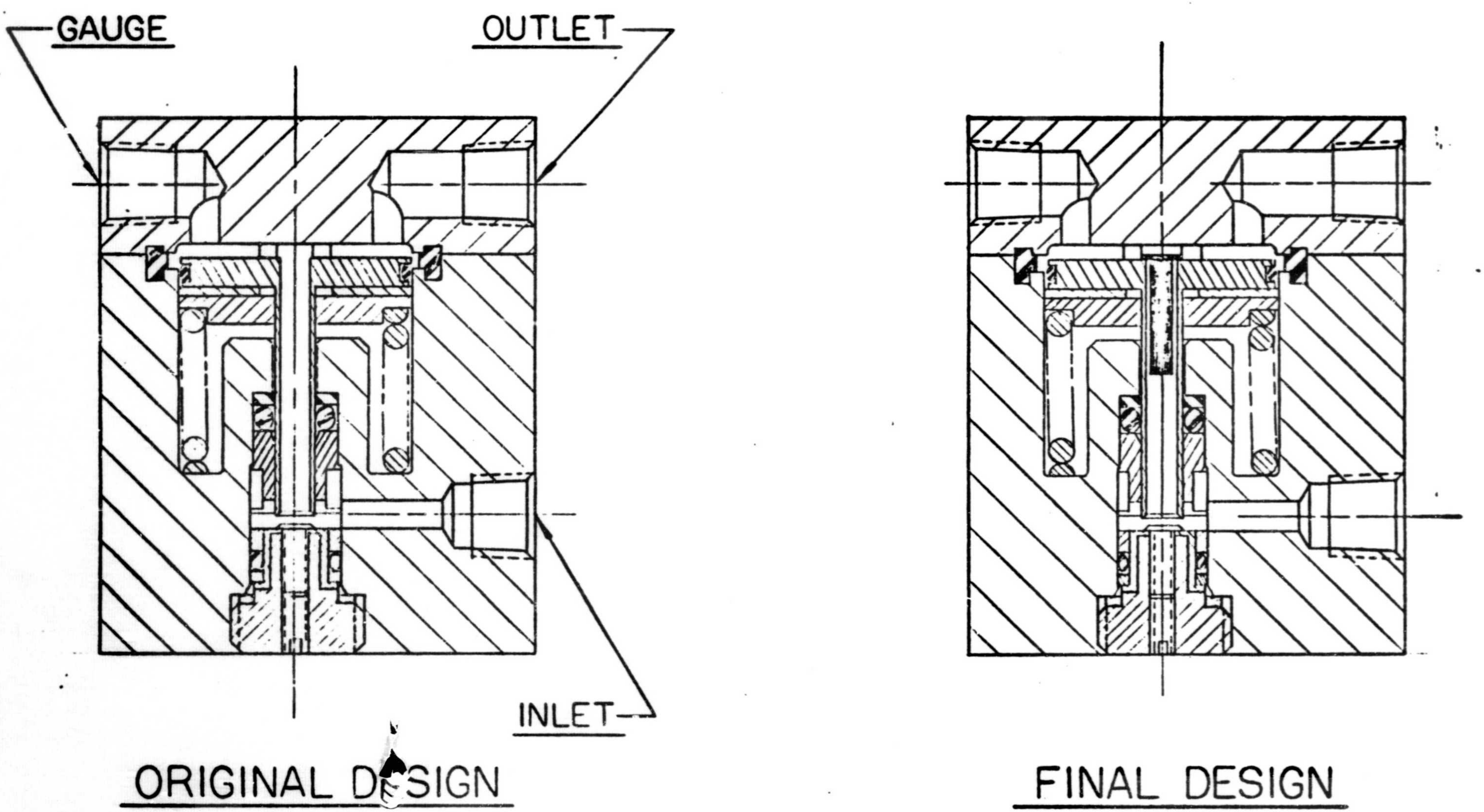
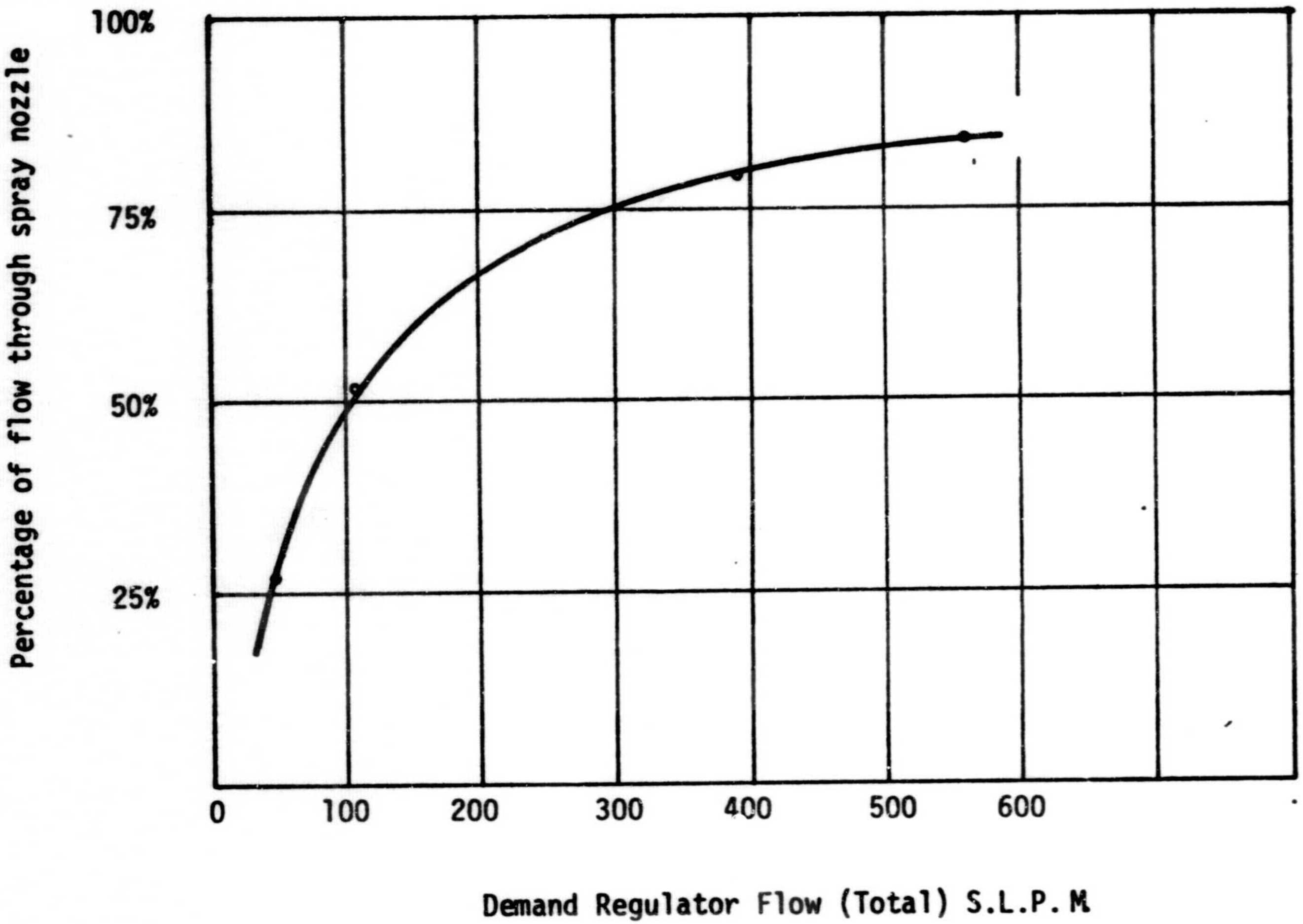


FIGURE 40



MODIFICATION OF PRESSURE REDUCER TO ELIMINATE SQUEAL

FIG. 41



100%
75%
50%
25%
Percentage of flow through spray nozzle
0
100
200
300
400
500
600
Demand Regulator Flow (Total) S.L.P.M

Figure 42

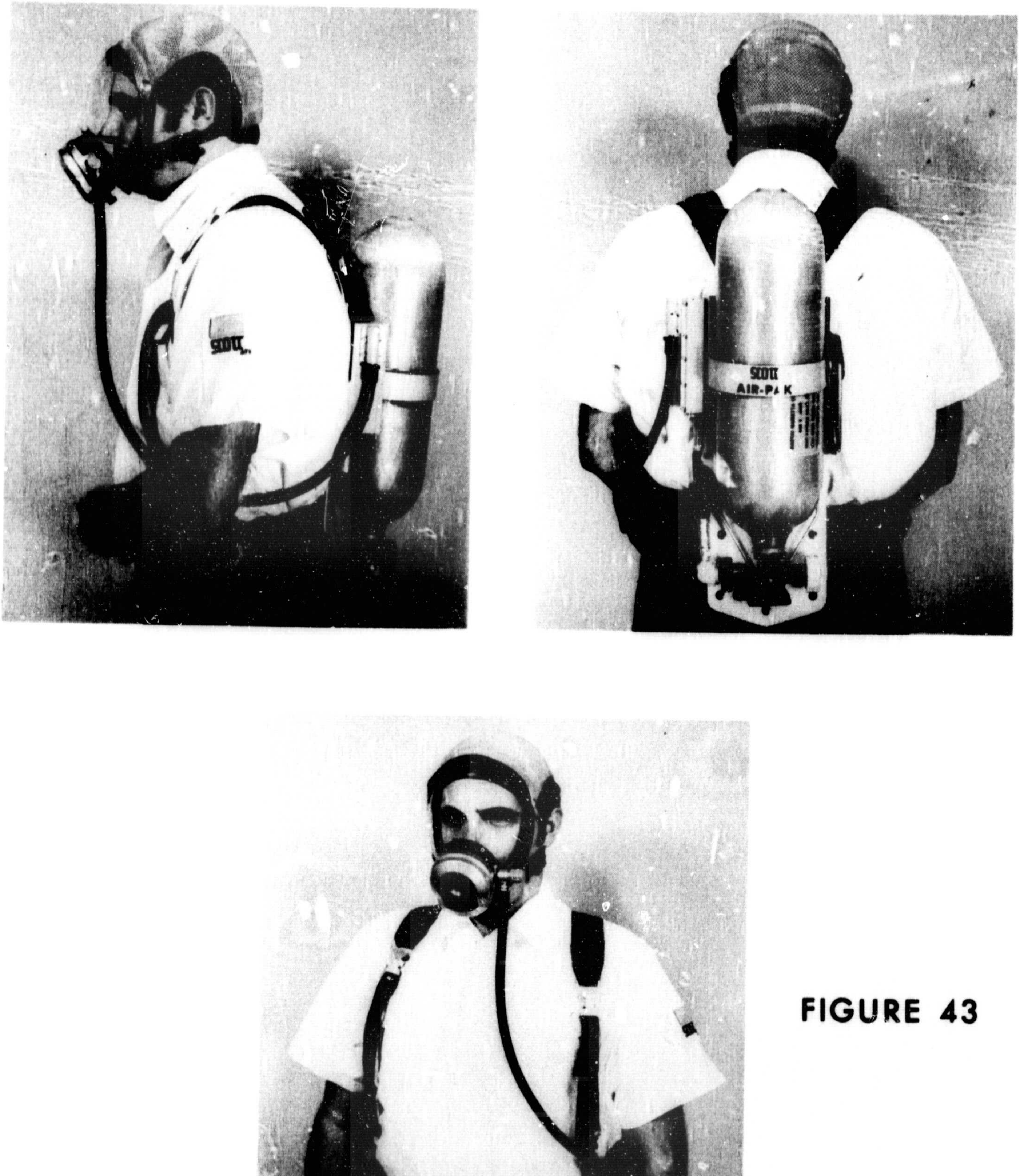


FIGURE 43

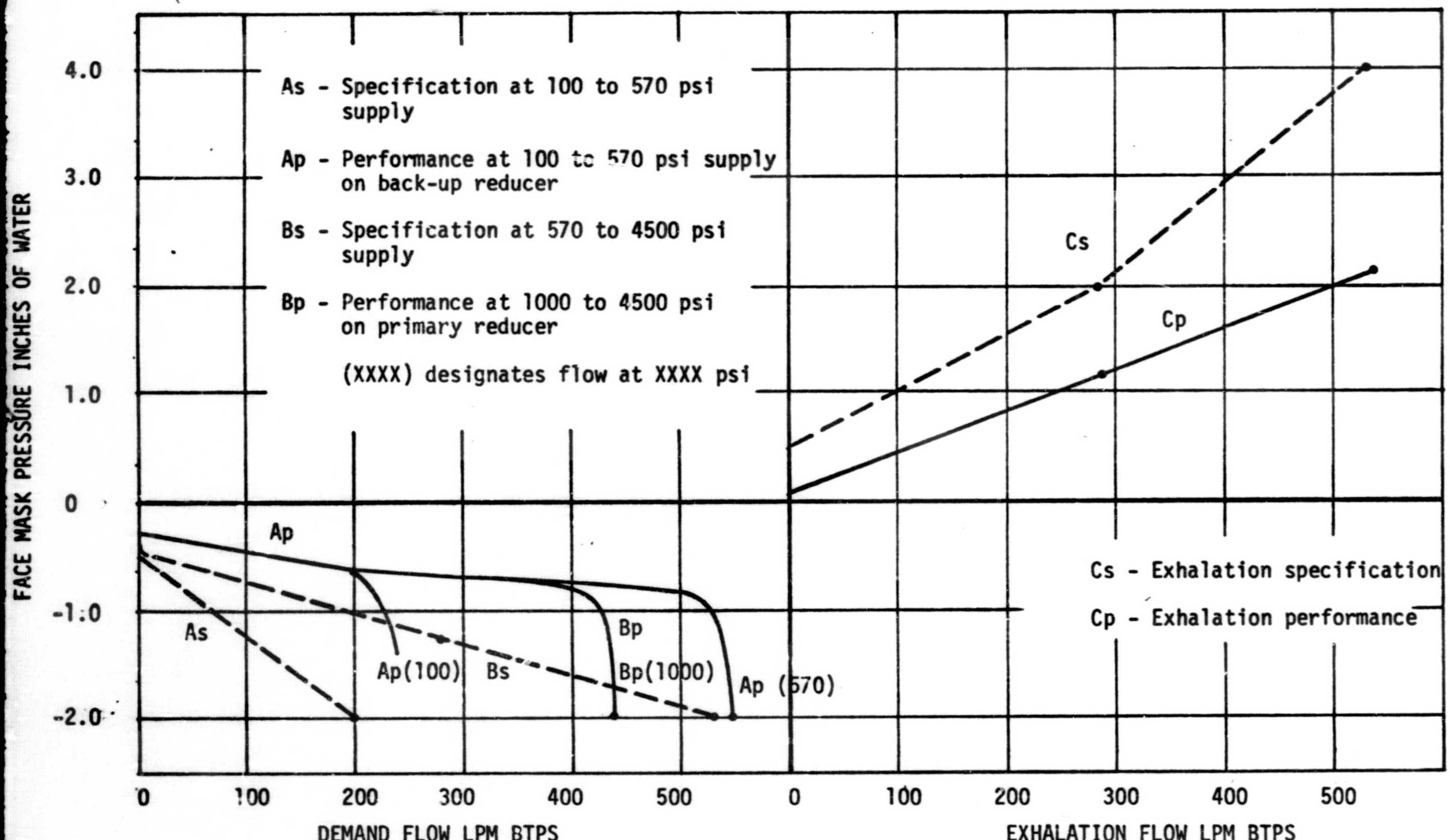


FIGURE 44
FINAL SYSTEM PERFORMANCE